جامعة الكويت
KUWAIT UNIVERSITY

KUWAIT UNIVERSITY-FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

GENERAL PHYSICS II LABORATORY MANUAL

PHYS 107-127

Electricity and Magnetism

Prepared By

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CONTENT

LABORATORY COURSE OUTLINE

COURSE NUMBER: 0430107 & 0430127
COURSE TITLE: General Physics Lab II
CREDITS: (0-3-1)
PREREQUISITES: PHYS 102 or PHYS 122 (Concurrent);
PHYS 105 or PHYS 125

CATALOGUE DESCRIPTION

Experiments in the basics of electric circuits with emphasis on analysis and overall understanding of some basic aspects of electromagnetism.

OBJECTIVES

- To enhance the understanding level of concepts in electricity, magnetism, and simple electrical circuits.
- To become acquainted with the related instrumentations and experimental techniques.
- To develop skills in communication and ability to work in groups.
- To enhance ability in experimental design, data and error analysis and report writing.

LEARNING OUTCOMES

Upon the completion of the laboratory course students should be able to

- Acquire knowledge of experimental techniques related to the concepts of electricity, magnetism, and simple electrical circuits.
- Demonstrate competence in proper data collection methods, graphical representation of data, data analysis and interpretation of results.
- Demonstrate analytical and critical thinking abilities.

LEARNING & TEACHING METHODS

- There will be a three-hour session data collection, analysis, interpretation of results, preparation, and submission of the lab report in its final form.
- Nine experiments from the following list will be conducted by each student, individually or in groups.
- The active participation and diligence shown by students in handling instruments and performing the practical work, as well as the degree of leadership in the group work, will be assessed by the instructor through observation and communication.
- Final exam that includes both experimental and theoretical questions will be held at the end of the term.

EXPERIMENTS

Experiment	Essential Physical Concepts
1. Ohm's Law	Usage of analog experimenter design, electrical measuring instruments. Study of *I-V* characteristics of resistors.
2. Tungsten Filament	Study of *I-V* characteristic of Tungsten filament.
3. Resistors in Series and Parallel	Studying circuits of resistors in different combinations. Equivalent circuits, current and voltage distribution in series and parallel circuits of resistors.
4. Kirchhoff's Rules	Understanding & Applying Kirchhoff's rules for multi-loops circuits of combined resistors.
5. Capacitor Charging	Analyzing the process of charging a capacitor and capacitor's voltage variation with time. Determination of time-constant of *R-C* circuit.
6. Capacitor Discharging	Study of capacitor's voltage variation with time when it is discharged through a resistor. Determination of time-constant of *R-C* circuit.
7. Series & Parallel capacitors	Study of circuits of capacitors in different combinations. Equivalent circuits, voltage distribution in series and parallel circuits of capacitors.
8. Electron Charge to Mass Ratio (e/m Ratio)	Concept of a charged particle moving in a uniform magnetic field.
9. *R-L* Circuit	Study of the relation between the total input signal and the voltages across the resistor and the inductor including the phase shift. Determination of Inductance of an inductor.
10. Transformer	Study the operation of a transformer. Effect of core configuration on the voltage gain. Comparing step-up and step-down transformers and between no-load and full-load operation.

RESOURCES

1. Laboratory Manual. (Electricity and Magnetism – General Physics Lab II (2017)
2. University Physics (15e), H. D. Young and R. A. Freedman, Pearson (2020)

ATTENDANCE REQUIREMENTS

Attendance in all lab sessions is mandatory. The assigned marks for attendance will be deducted from any grade of any lab session skipped by the students.

LABORATORY REPORT SUBMISSIONS

Lab reports must be submitted at the end of each session (or by the indicated deadline).

Penalties will be imposed for late submissions as follows: deduction of 10% of the lab marks for each late day up to a maximum of 3 days. No late lab report, for which no extension has been granted, will be accepted after 3 days past the deadline.

LAB ASSESSMENT

Student Attendance	5%
Instructor's Opinion	5%
Quizzes	10%
Laboratory Report (Average)	40%
Final exam	40%

PLAGIARISM

Plagiarism is a serious academic offence. Put simply, plagiarism is an action whereby one claims as his own, work or ideas of other people with the intent to deceive. Examples of plagiarism are:

- The use of published or unpublished work of others either as a whole or in parts (such as paragraphs or sentences), which includes books, journal articles, theses, websites, etc., without proper acknowledgement or referencing or without the use of quotation marks.

- Paraphrasing closely the work of others either as a whole or in parts without proper referencing.
- Copying computer files without proper acknowledgements.
- Use or submission of computer programs written by others without authorization.
- Claiming as your own work executed for you by some other person or agency.
- Scattering one's own comments through a text that has been substantially lifted from another source.

GUIDELINES TO LAB REPORT WRITING AND MARKING SCHEME

1- **Title page**

Use the cover page provided with each experiment in the manual to write your name, the name of your laboratory partner, the date, the section number, and the instructor's name.

2- **Statement of Objectives:** [**1 Marks**]

Student should outline the objectives of the experiment in his own words.

3- **Data and Analysis of Results:** [**6 Marks**]

- Concise presentation of data and results with detailed calculations.
- Properly scaled and titled graphs.
- Error analysis.

4- **Discussion and Conclusion**: **[3 Marks]**

- Begin by restating the goals of your experiment.
- Describe the methods you used in your experiment.
- Provide a summary of your final data.
- Analyze your final data.
- Mention the sources of errors and how to get better results.

Pre-laboratory session

OBJECTIVES

- To learn the difference between direct current and alternating current.
- To study the resistors color-coding system.
- To get familiar with experimenter design.
- To learn how to use multimeter for voltage, current, and resistance measurements.

DIRECT AND ALTERNATING CURRENTS

Direct current (DC) refers to a current that does not change direction with time. A Battery is one sort of a DC current source. A plot of a constant DC current versus time represents a horizontal straight line as shown in **Fig. 1**.

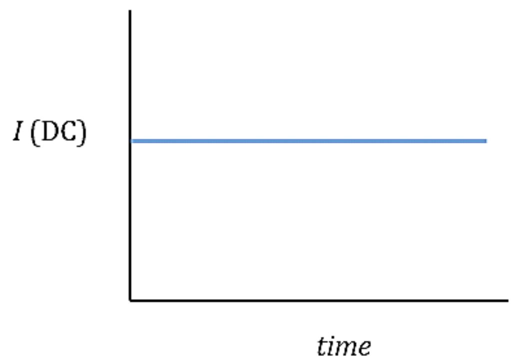

Fig. 1

Alternating current (AC), on other hand, refers to a current that change direction with time (oscillate). There are different types of AC currents: sinusoidal, square, triangular and others. The sinusoidal current (**Fig. 2**) is the most popular one among the others since it is the natural output of the commercial alternating current generators or *alternators*. Other types of AC currents are produced from the sinusoidal one, using some special electronic devices.

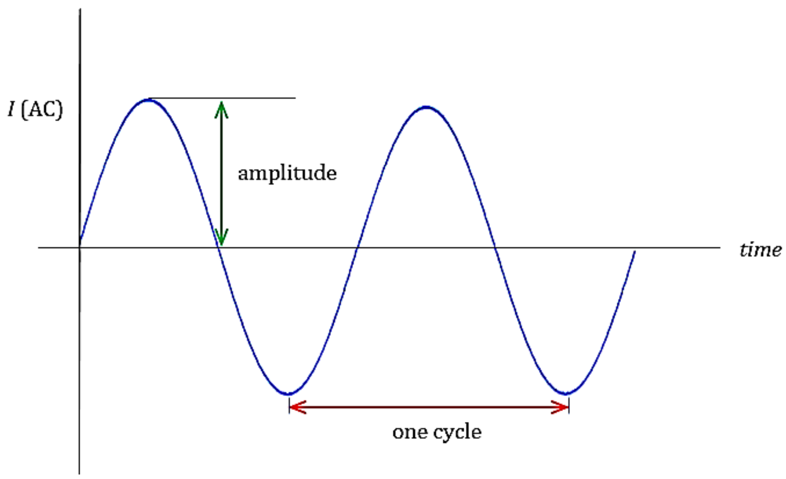

Fig. 2

RESISTORS COLOR-CODING SYSTEM

Resistors form the most basic and popular electric components used in electric circuitry. Since the size of resistors is small, color-coding system is adapted for the value of a resistor and the tolerance. So rather than writing the value of the resistor on it, color bands are used, forming a code representing the value of the resistor (**Fig. 3**).

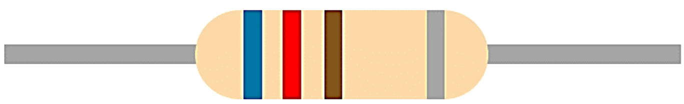

Fig. 3

Colors are numbered from $0-9$ according to **Table I**. Let the golden or silver band be to the right, and let x, y, and z represent the numbers of the first three colors (scanned from left to right), the value of the resister is found from

$$R = xy \times 10^z$$

That is, the numbers of the first two colors are written adjacently to form a 2-digit number multiplied by 10 raised to the power z.

The fourth color (if exists), which can be gold or silver, represents the tolerance (accuracy) in the value of the resistor. If it is gold, the tolerance is 5% of the resistance value, whereas if it is silver, the tolerance is 10%. If there is no fourth band, then the tolerance is 20%.

Table I

black	0
brown	1
red	2
orange	3
yellow	4
green	5
blue	6
violet	7
grey	8
white	9
gold	5%
silver	10%
No 4th band	20%

Example 1: Let the colors of a given resistor be: brown, black, red, and the fourth color be gold. Determine the value of the resistor and the tolerance.

Solution: The numbers of the four colors from the color-coding list (successively) are: $1, 0, 2$ and 5% Therefore the resistance

$$R = 10 \times 10^2 = 1000\ \Omega$$

The tolerance equal

$$5\% \times 1000 = 50\ \Omega$$

This means that the resistance value falls within $1000 \pm 50\ \Omega$, i.e., the actual value of the resistor ranges from $950\ \Omega$ to $1050\ \Omega$.

THE ELECTRONIC DESIGN EXPERIMENTER

The electronic design experimenter is a device used for designing some basic electronic circuits. It consists mainly of 7 units as shown in **Fig. 4**:

1. POWER switch: Turns the trainer on and off.
2. POWER SUPLLY: consists of positive control (range: 1 V - 15 V), which adjusts the output of the positive power supply, and negative control (range: -1 V – (-15) V), which adjusts the output of the negative power supply, and three connectors: POS, GND, and NEG which stands for positive, ground, and negative.
3. LINE FREQUENCY: consists of three connectors and supplies a 50 Hz 15 V (AC) voltage.
4. GENERATOR: Supplies a variable frequency AC voltage (range: 0 Hz – 2 kHz and can be upgraded to 20 kHz by setting the range switch to 10X).
5. 1 kΩ variable resistor: consists of a control along with three connectors.
6. 100 kΩ variable resistor: consists of a control along with three connectors.
7. BREADBOARD: consists of 4 units: two horizontal lines of 50 internally connected connectors (one at the top and the other at the bottom); two blocks each consisting of a group of 5 vertical internally connected connectors.

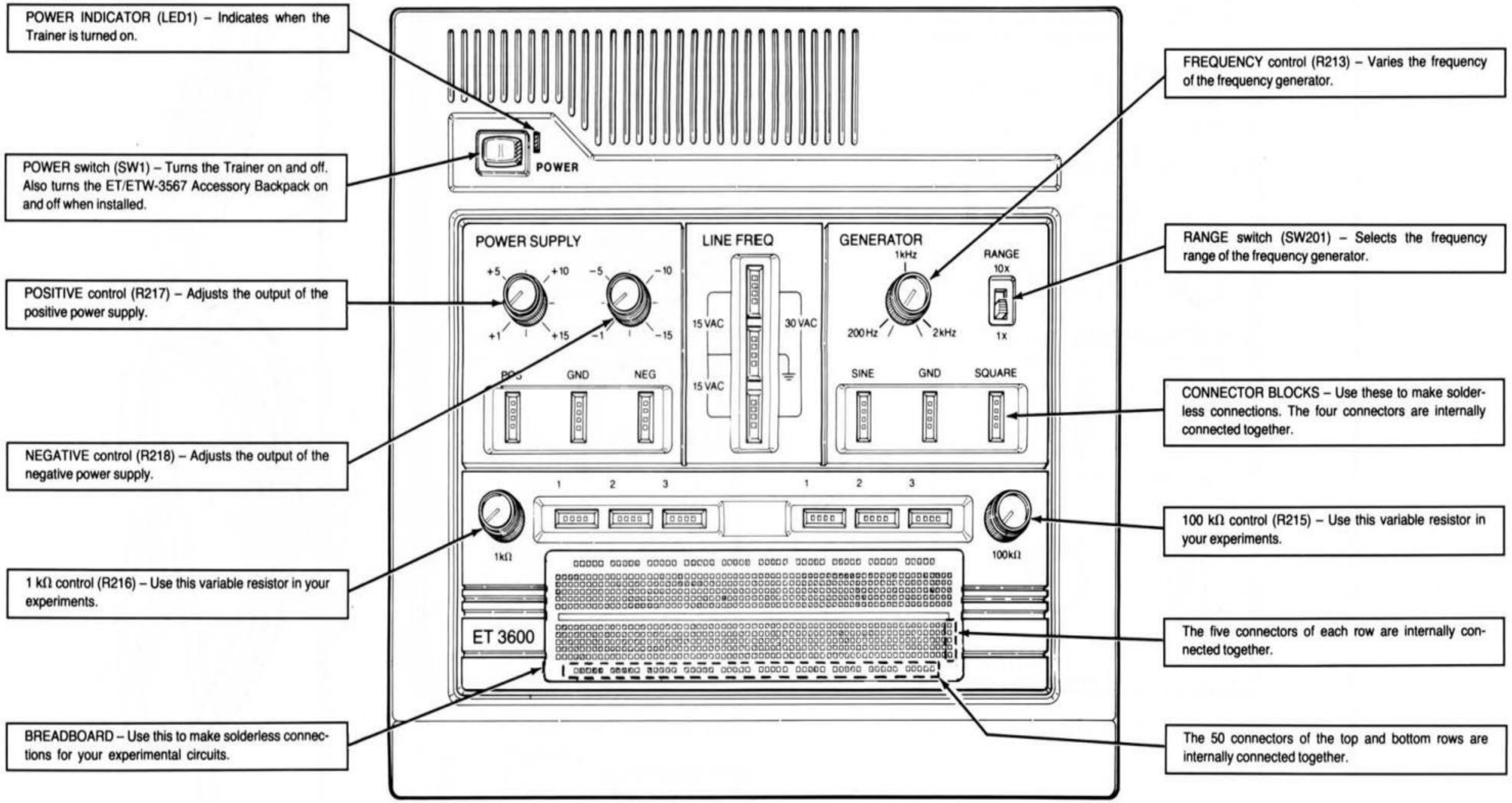

Fig. 4: Electronic Design Experimenter

DIGITAL MULTIMETER

Many of the electrical measurements in this lab are done using a digital multimeter (DMM). A DMM can be used to measure current, voltage, or resistance as explained below.

MEASURING VOLTAGE

a) Set the switch of the DMM to the voltage position ($\bar{V}$ for DC or $\tilde{V}$ for AC).
b) Plug the black probe of the multimeter into the COM socket, and the red probe into the V socket.
c) **Connect** the probes of the multimeter **parallel to the resistor** (**Fig. 5**).

(**Note:** If red probe is connected to a lead of higher potential and the black probe is connected to a lead of lower potential, the multimeter reads positive value, otherwise it reads negative value)

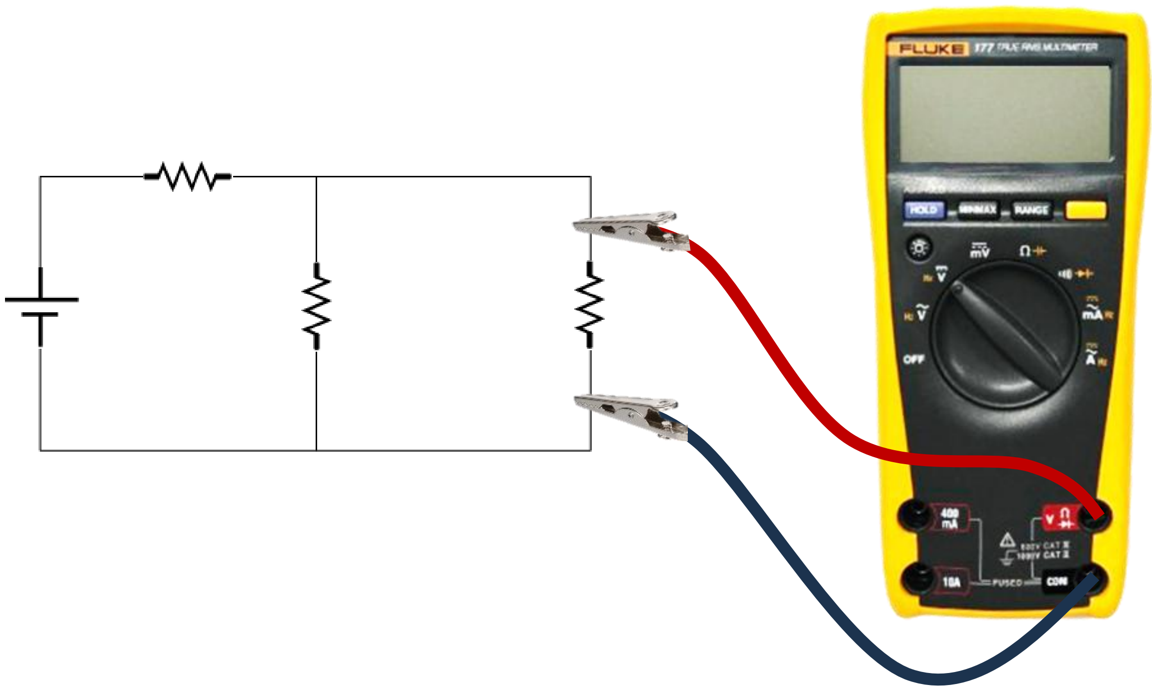

Fig. 5

MEASURING CURRENT

a) Set the switch of the multimeter to the current position ($\bar{A}$ for DC or $\tilde{A}$ for AC).

b) Plug the black probe of the multimeter into the COM socket, and the red probe into the mA socket (or the A socket if the estimated current values are Ampere).

c) **Connect** the probes of the multimeter **in series to the resistor**, (**Fig. 6**).

(**Note:** If the current enters the multimeter through the red probe the multimeter reads positive value, otherwise it reads negative value)

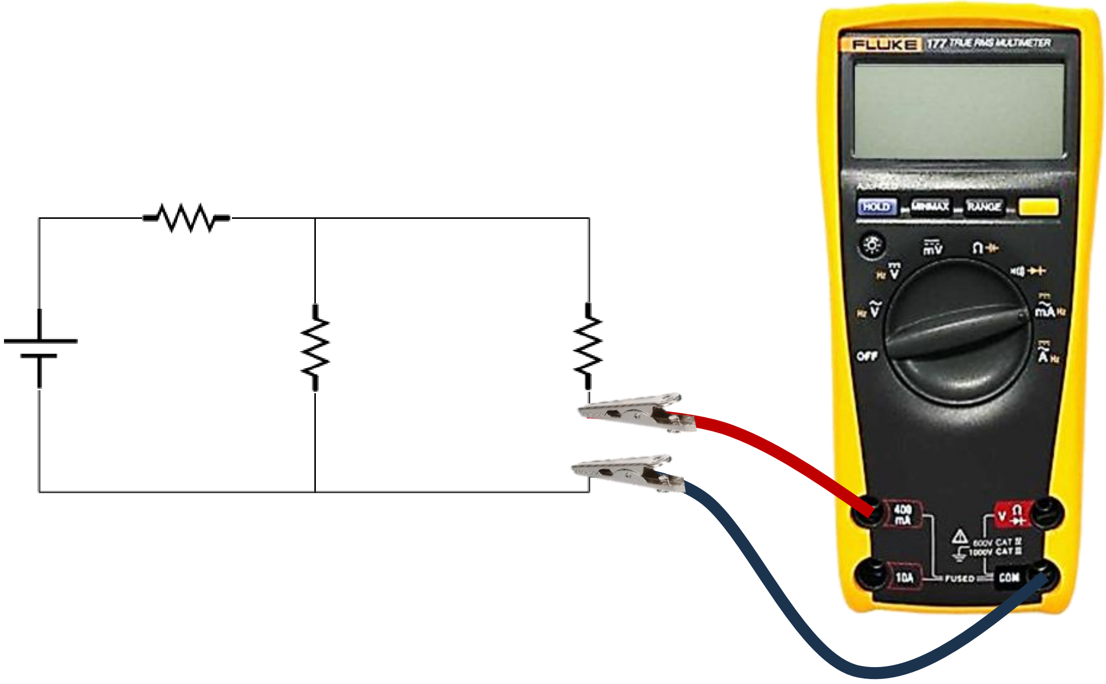

Fig. 6

MEASURING RESISTANCE

a) **Disconnect** the resistor from the circuit (or disconnect one lead only).

b) Set the switch of the multimeter to the Ohm position (Ω).

c) Plug the black probe into the COM socket, and the red probe into the V-Ω socket.

d) Connect the two probes of the multimeter **in parallel to the resistor** (**Fig. 7**).

(**Note:** To measure the resistance of a resistor, it should be disconnected from the circuit (or one lead of it at least should be disconnected)

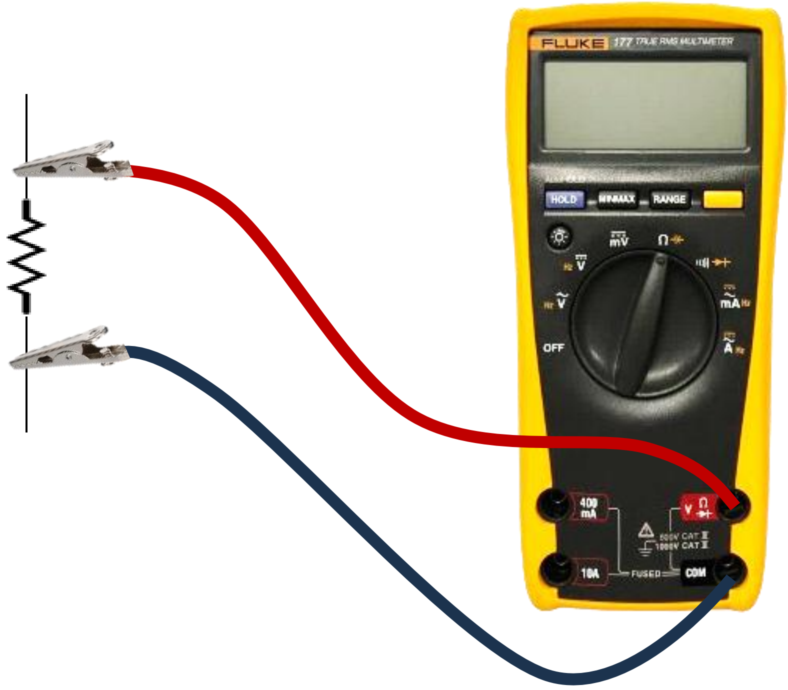

Fig. 7

Experiment One: Ohm's Law

Objectives

The objective of this experiment is to study Ohm's law by examining the *I*-*V* characteristics of a fixed (carbon) resistor.

Introduction

When a potential difference V_s is applied across a device such as a resistor, a current I flows through it (the current comes out of the POS terminal, goes through the circuit then goes back to the GND terminal) (**Fig. 1**).

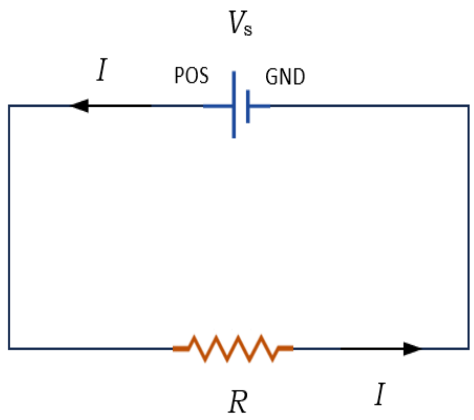

Fig. 1

Ohms Law: Ohm's law states that the amount of current I passing through a device is proportional to the applied voltage V. Mathematically, this is written as

$$V = RI \tag{1}$$

where R, which is the constant of proportionality, denotes the resistance of the device. A device that follows this relation is said to obey Ohm's Law and is called an **Ohmic device**. **Figure 2** shows the current versus voltage relation

($I - V$ characteristic) of an Ohmic device, where the slope of the line equals the recipricol of R (slope $= 1/R$).

In fact, all ohmic devices obeys ohm's law for a limited range of the applied voltage, since beyond a certain limit the device gets over heated thereby it looses its original charecteristics and won't obey ohms law any more. It worth mentioning that if a device doesn't obey ohm's law, Eq. (1) still hold given that R is not constant.

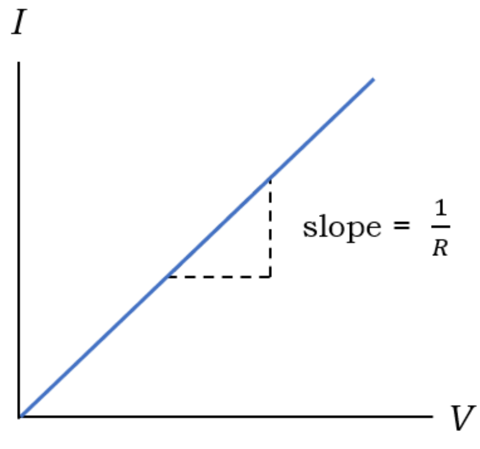

Fig. 2: *I-V* curve for an ohmic device

Equipment

- ETW-3600 Analog Trainer
- 560 Ω or 620 Ω resistor
- Multimeter
- Wires

Procedure

1- Measure the resistance of the resistor. Record it above **Table I**.

2- Mount the 620 Ω resistor on the breadboard, then connect its leads to the power supply terminals (**POS** and **GND**) using wires, as shown in **Fig. 3**.

3- Connect the multimeter across the **POS** and **GND** terminals and set the value of the source voltage V_s according to **Table I (Fig. 3)**.

4- For each value of V_s measure the volatge across the resister (V_R) and the current through the resister (I_R) and record them in **Table I (Figs. 4 & 5)**.

5- Using Ohm's law calculate the value of R.

6- **Plot a graph** of I_R versus V_R and determine the value of R from the slope.

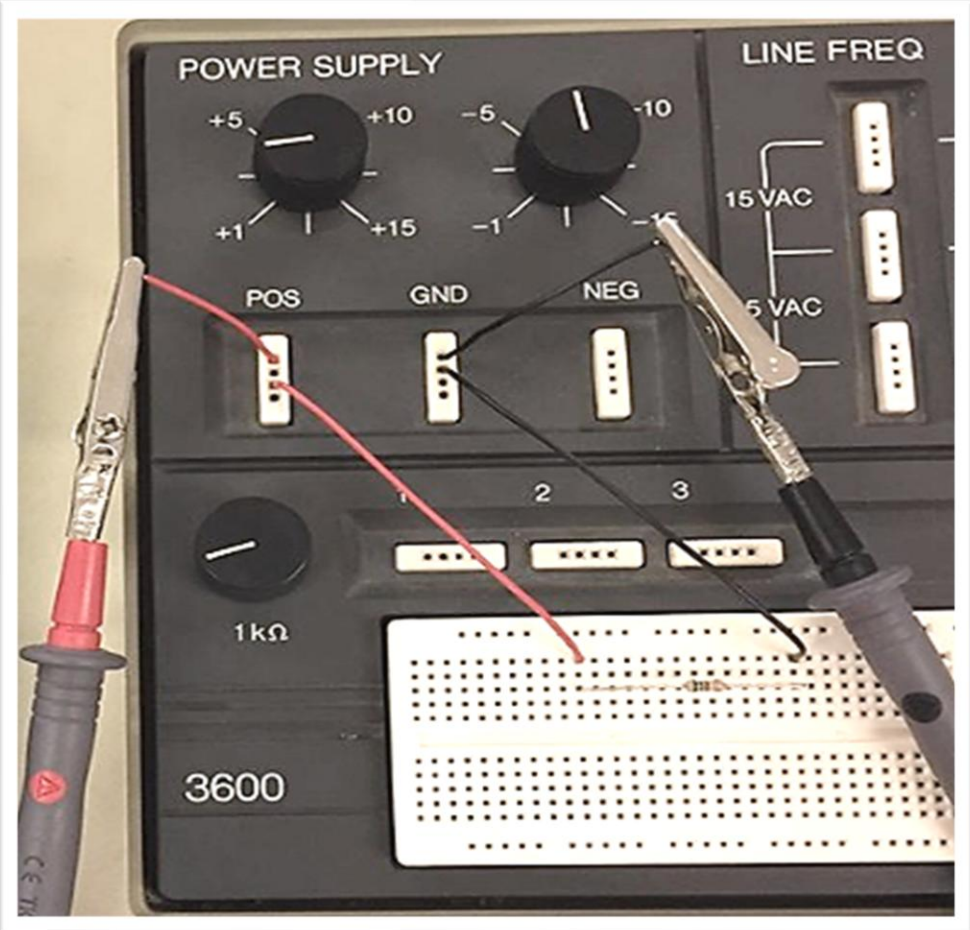

Fig. 3: How to measure V_s

Note: If red probe is connected to the POS connector and black probe is connected to the GND connector, the multimeter reads positive value, otherwise it reads negative value)

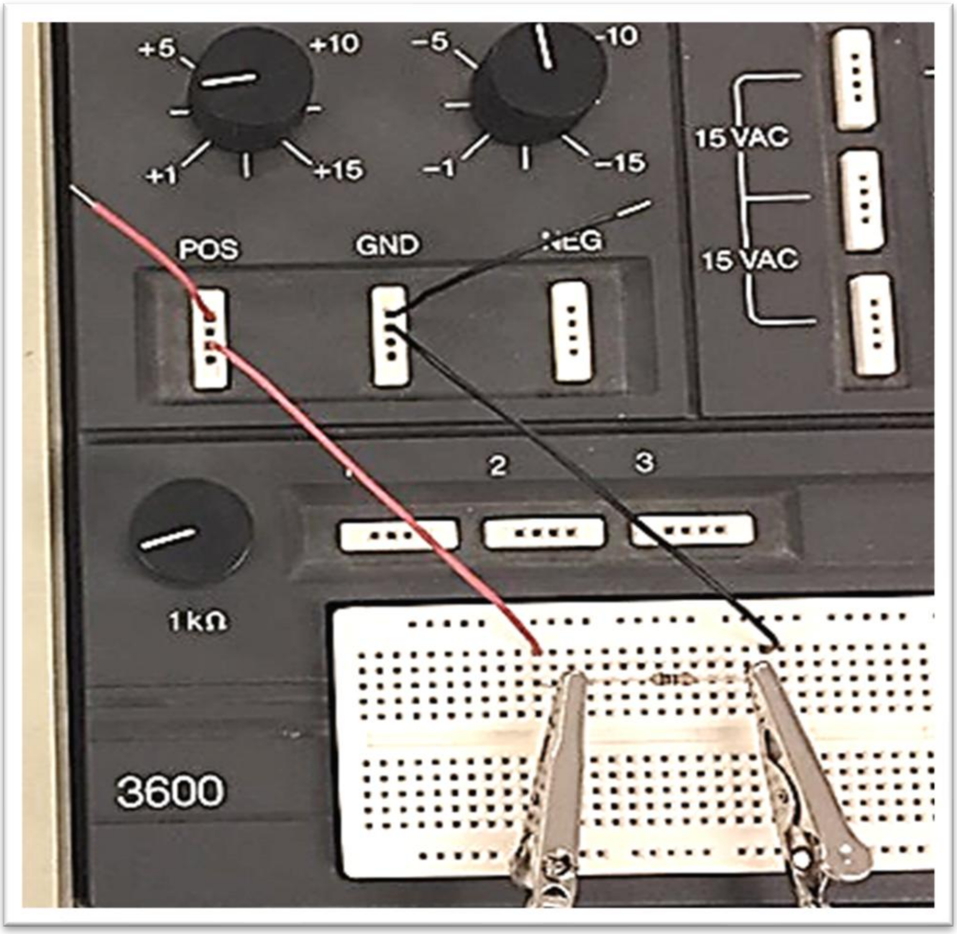

Fig. 4: How to measure V_R

(**Note:** If red probe is connected to a lead of higher potential and the black probe is connected to a lead of lower potential, the multimeter reads positive value, otherwise it reads negative value)

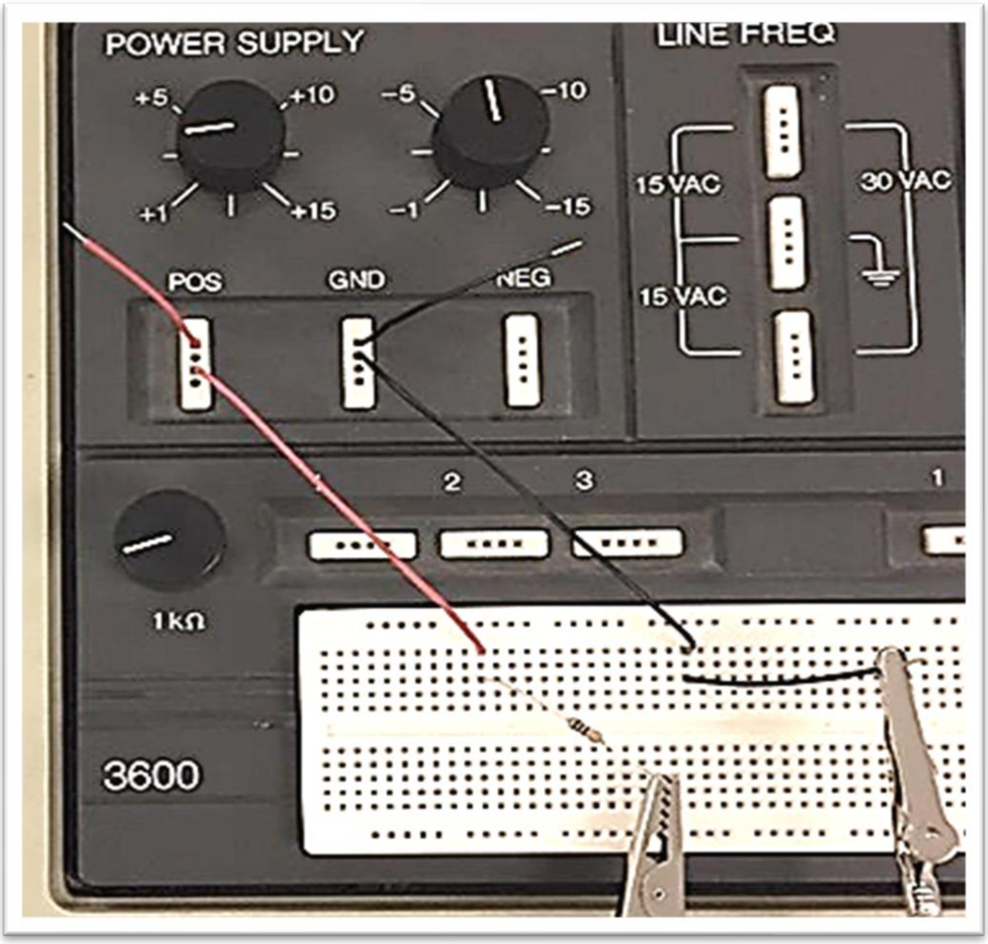

Fig. 5: How to measure I_R

(**Note:** If the current enters the multimeter through the red probe the multimeter reads positive value, otherwise it reads negative value)

Section: ....

Date:............................

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Exp. No. (1)

OHM'S LAW

Resistor

Student name:..

Student ID:..

Instructor name:..

Group no.:

Objectives

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………

………

Data And Analysis of Results

- Color coded value: R_{coded} =……….. Ω
- Measured value: R_{meas} =……….. Ω

Table I

V_s(V)	V_R(V)	I_R(mA)	$R(\Omega)$
2.0			
4.0			
6.0			
8.0			
10.0			
12.0			

-

- Average value of R from the table, R_{avg} =……… Ω
- Value obtained from the graph, R_{graph} =……… Ω
- Percentage error in the resistance:

$$\left|\frac{R_{graph}-R_{meas}}{R_{meas}}\right| \times 100 = \ldots\ldots\ldots\ldots\%$$

- For one of the $\boldsymbol{V_s}$ values in the table, measure the current from the left lead of the resistor (I_L = ...mA), then measure it from the right lead (I_R = ... mA). Compare the two values. What do you conclude?

  ....

Questions

1- How does V_R change with I_R?...

2- Is a resistor an ohmic device? Explain.

   ....

3- If a device is not ohmic, does the relation $R = V/I$ still hold?....................

4- Does an ohmic device obey ohm's law for indefinite voltage values?..........

   Explain...

Discussion And Conclusion

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Experiment Two: Non-ohmic Device

Tungsten Filament

Objectives

- To study the *I-V* characteristic of a Tungsten filament as a non-ohmic device.
- To understand the difference between ohmic and non-ohmic devices.

Introduction

Tungsten (also called wolfram) is a chemical element; it has symbol W and atomic number 74. Tungsten is a hard steel-grey metal that is often brittle and hard to work. Because it retains its strength at high temperatures and has a high melting point, elemental Tungsten is used in many high-temperature applications, such as incandescent light bulb, cathode-ray and vacuum tube filaments, heating elements, tube, and rocket engine nozzles.

As we observed in Exp.1, the resistance of an ohmic device remains constant when the applied voltage is varied. However, for some other materials, such as the Tungsten filament, the resistance (R_F) increases (due to the increase of its temperature) when the applied voltage (V_F) across the filament increases. Therefore, the current (I_F) is not directly proportional to the applied voltage; hence, a plot of I_F versus V_F yields a nonlinear curve (**Fig. 1**) and the Tungsten filament is called a non-ohmic device.

Equipments

- ETW-3600 Analog Trainer
- Tungsten filament
- Resistor, 220 Ω
- Multimeter.

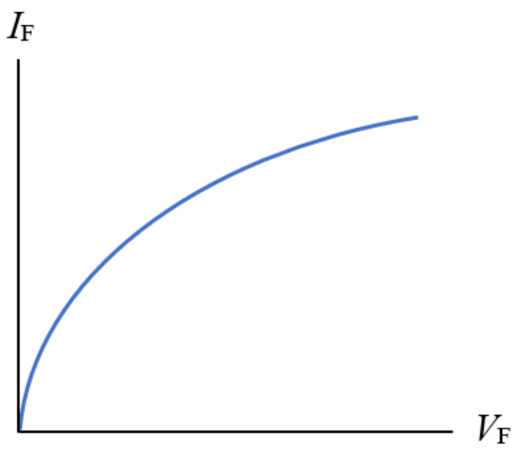

Fig. 1: *I*-*V* curve for the Tungsten filament

Procedure

1- Implement the circuit in **Fig. 2** on the breadboard as shown in **Figs. 3&4**.

2- Corresponding to the power supply values V_s listed in **Table I**, measure the voltage V_R across the resistor, and the voltage V_F across the filament.

3- For each value of V_s, calculate the value of I_F (which equals I_R) using Ohm's law ($I_R = V_R/R$), and record it in the table.

4- Calculate R_F using Ohm's law for each value of V_s and record it in the table.

5- **Plot a graph** of I_F versus V_F.

6- Find the resistance of the filament at the two points A ($V_F = 3.0$ V) and B ($V_F = 6.0$ V). Write your results in the allocated space under **Table I**.

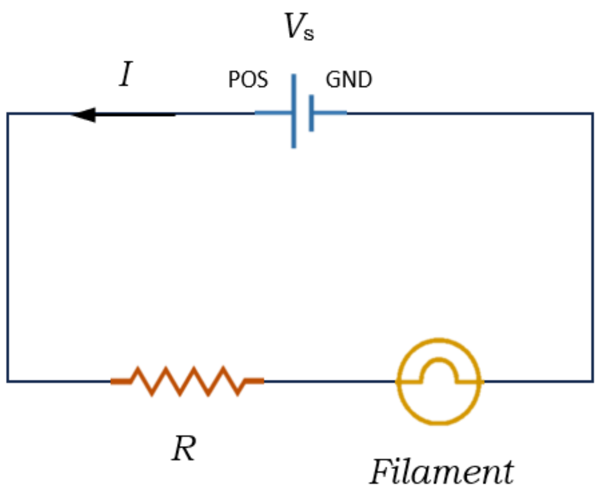

Fig. 2

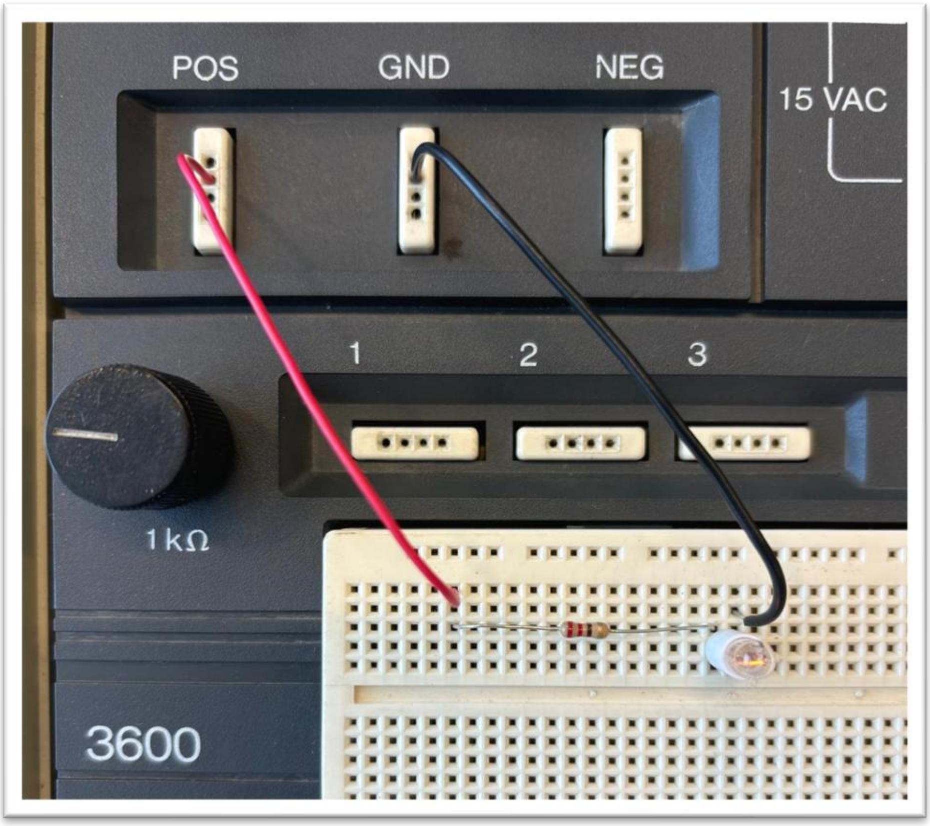

Fig. 3

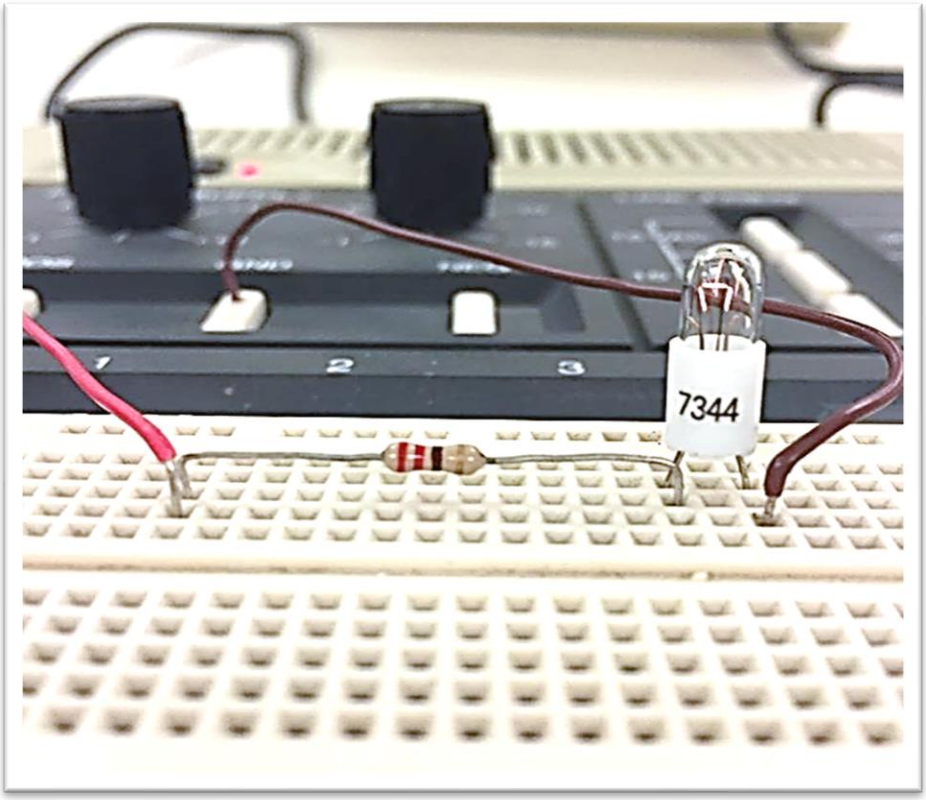

Fig. 4

Section: ....

Date:...........................

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Exp. No. (2)

NON OHMIC DEVICES

Tungsten filament

Student name:...

Student ID:...

Instructor name:..

Group no.:

Objectives

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....

....

Data and analysis of results

Table I

V_s (V)	V_R (V)	V_F (V)	$I_F = \frac{V_R}{R}$ (mA)	$R_F = \frac{V_F}{I_F}$ (Ω)
2.0				
4.0				
6.0				
8.0				
10.0				
12.0				

Resistance at point A: R_A = ...

Resistance at point B: R_B = ...

Questions

1- Does the graph of I_F vs V_F show a directly proportional relation? Explain.

....

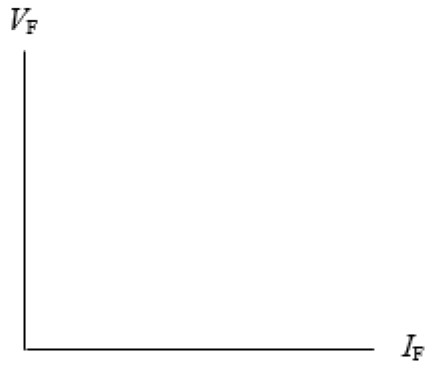
2- Does the resistance of the filament increase, decrease, or it is constant as V_F increases? Explain.

....

3- Is the Tungsten filament an ohmic device? Explain.

....

4- Using the axes below, draw V_F vs I_F.



Discussion and conclusion

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Experiment Three:
Series and Parallel Resistors

Objectives

- To understand the relation among voltages, currents, and resistances for resistors connected both in series and in parallel.
- To determine the equivalent resistance for both series and the parallel networks of resistors.

Introduction

Resistors in Series: When two resistors $\boldsymbol{R_1}$ and $\boldsymbol{R_2}$ are connected in series to each other and to a power supply $\boldsymbol{V_s}$ (**Fig. 1**), then based on the conservation of energy, the sum of the potential differences ($\boldsymbol{V_1}$, $\boldsymbol{V_2}$) across the resistors equals the power supply voltage, i.e.,

$$V_s = V_1 + V_2 \tag{1}$$

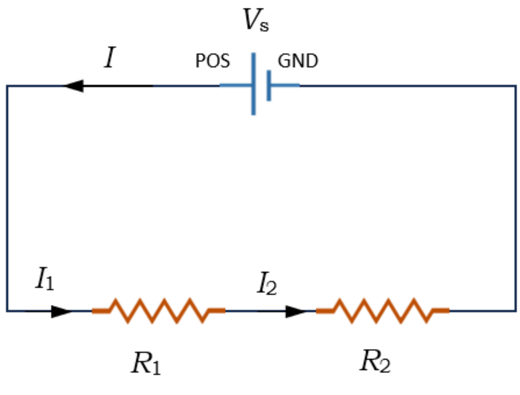

Fig. 1: Two series resistors

whereas the currents ($\boldsymbol{I_1}$, $\boldsymbol{I_2}$) through the resistors are the same and equal to the current $\boldsymbol{I}$ delivered by the power supply i.e.,

$$I = I_1 = I_2 \tag{2}$$

Using Eq.(1) it can be proved that the equivalent resistance R_{eq} of the combined resistors equals the sum of the resistances as:

$$R_{\mathrm{eq}} = R_1 + R_2 \tag{3}$$

Based on Eq.(3), *the equivalent resistance for two resistors connected in series is greater than the greatest one.*

Resistors in Parallel: When two resistors are connected in parallel to each other and to a power supply V_s (**Fig. 2**), they share the same potential difference such that

$$V_s = V_1 = V_2 \tag{4}$$

And (based on the conservation of charge) the current I delivered by the power supply equals the sum of currents (I_1, I_2) through individual resistors:

$$I = I_1 + I_2 \tag{5}$$

Here, Eq.(5) can be used to prove that the equivalent resistance R_{eq} of the combined resistors can be obtained from

$$\frac{1}{R_{\mathrm{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} \tag{6}$$

Based on Eq.(6), *the equivalent resistance for two resistors connected in parallel is less than the smallest one*.

Equipments

- ETW-3600 Analog Trainer
- Resistors: 390 Ω, 560 Ω, 1.0 kΩ.
- Multimeter
- Wires.

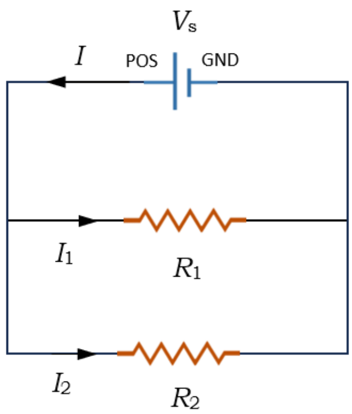

Fig. 2: Two resistors in parallel

Procedure

Part One: **Series resistors** (R_1 = 560 Ω, R_2 = 390 Ω)

1. Measure R_1 and R_2 and record the values in **Table I**.
2. Implement the circuit given in **Fig.1** as shown in **Fig.3**.
3. Set the power supply voltage to $\boldsymbol{V_s} = \mathbf{10\ V}$.
4. Measure the equivalent resistance R_{eq} and record in **Table I**.
5. Measure the currents I_1 and I_2 passing through each resistor, and the current I delivered by the power supply and record the data in **Table I**.
6. Measure the potential differences V_1 and V_2 across R_1 and R_2, and record the data in **Table I**.
7. Calculate R_{eq}, I, I_1, I_2, V_1, and V_2 using relevant equations and record the values in **Table II**.

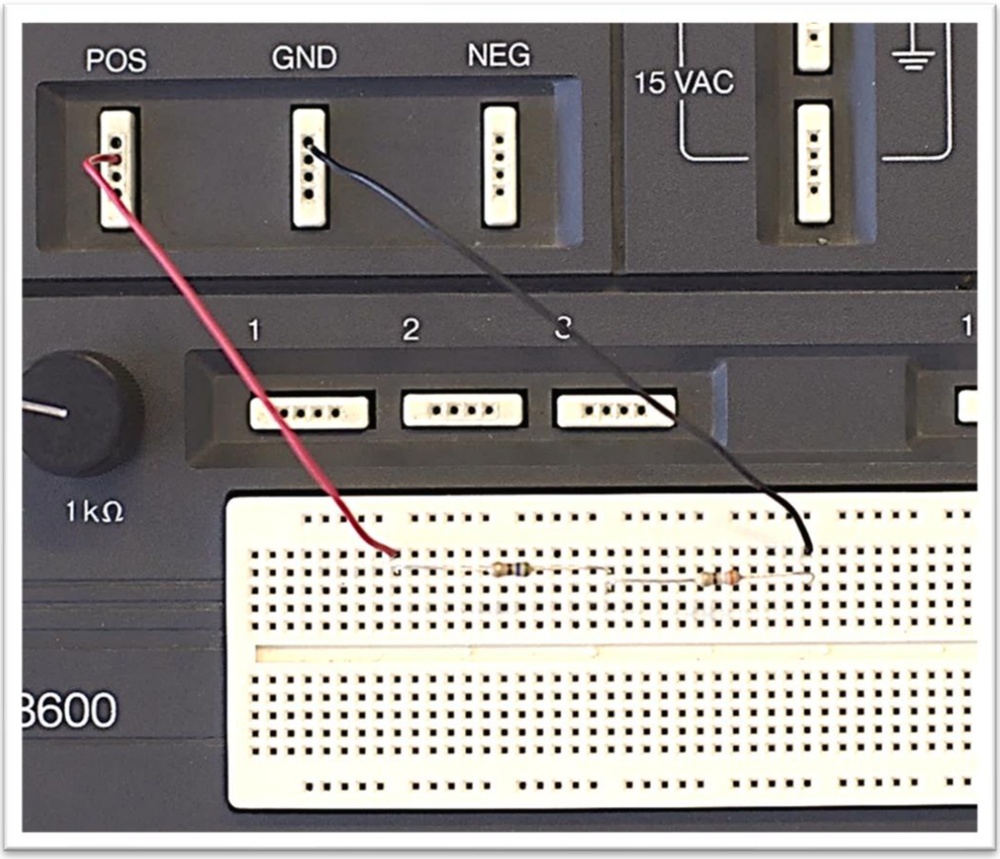

Fig. 3: Series circuit

Part Two: **Parallel Resistors** (R_1 = 560 Ω, R_2 = 1.0 kΩ)

1. Measure R_1 and R_2 and record the values in **Table III**.
2. Implement the circuit given in **Fig.2** as shown in **Fig.4**.
3. Set the power supply voltage to $\boldsymbol{V_s = 4.0}$ **V**.
4. Measure the equivalent resistance R_{eq}, and record it in **Table III**.
5. Measure the currents I_1 and I_2 passing through each resistor, and the current I delivered by the power supply and record the data in **Table III**.
6. Measure the potential differences V_1 and V_2 across R_1 and R_2 and record the data in **Table III**.
7. Calculate R_{eq}, I, I_1, I_2, V_1, and V_2 using relevant equations and record the values in **Table IV**.

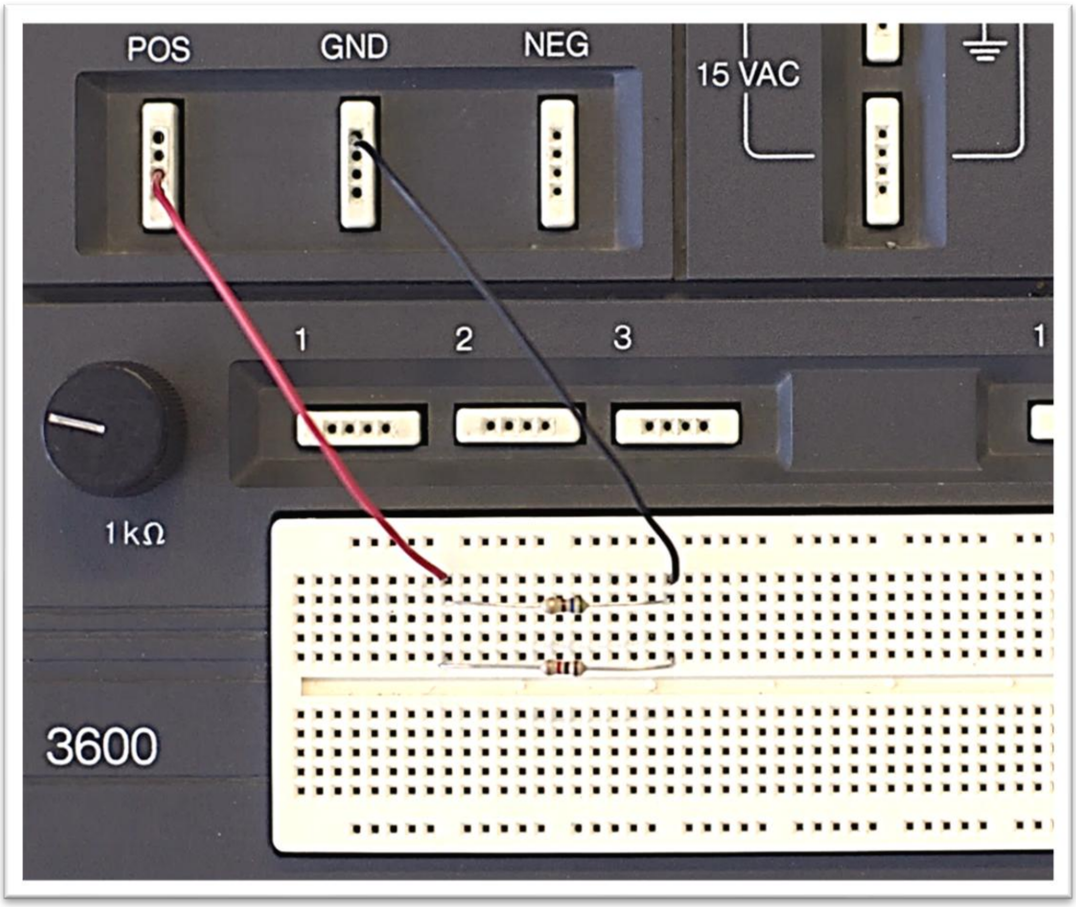

Fig. 4: Parallel circuit

Part Three: Combination of series & parallel resistors:

(R_1 = 560 Ω, R_2 = 390 Ω, R_3 = 1.0 kΩ)

1. Measure R_1, R_2 and R_3. Record the values in **Table V**.
2. Implement the circuit given in **Fig.5**.
3. Set the power supply voltage to $\boldsymbol{V_s = 9.0}$ **V**.
4. Measure the equivalent resistance R_{eq}, and record it in **Table V**.
5. Measure the current I delivered by the power supply and record the value in **Table V**.
6. Measure the potential differences V_1, V_2, and V_3 across corresponding resistors and record the data in **Table V**.
7. Perform the requirements below **Table V**.

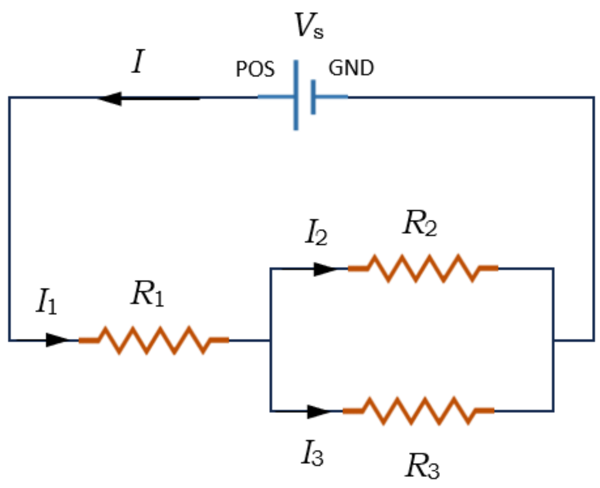

Fig. 5: Combination of series & parallel resistors

Section: ....

Date:............................

جامعة الكويت
KUWAIT UNIVERSITY

Exp. No. (3)

SERIES & PARALLEL

resistors

Student name:..

Student ID:..

Instructor name:...

Group no.:

Objectives

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Data and analysis of results

Part One: Resistors in series: (coded values: R_1 = 560 Ω, R_2 = 390 Ω)

Table I: (Measured values)

R_1 = ..., R_2 =.............. $\boldsymbol{V_s = 10\ \mathrm{V}}$

R_{eq} (Ω)	I (mA)	I_1 (mA)	I_2 (mA)	V_1 (V)	V_2 (V)

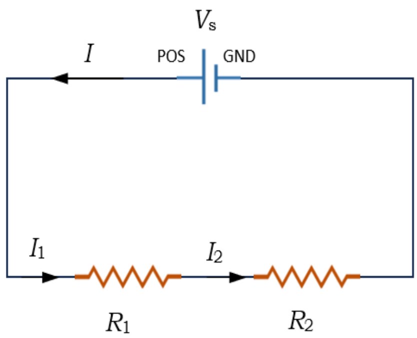

Table II: (Calculated values): **using the measured values of R_1 & R_2**

R_{eq} (Ω)	I (mA)	I_1 (mA)	I_2 (mA)	V_1 (V)	V_2 (V)

1. Compare the measured values with the calculated ones.

   ....

2. Using the measured values verify the relations for the voltage, current, and resistance given for the series circuit.

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Part Two: Resistors in parallel: (coded values: R_1 = 560 Ω, R_2 = 1.0 kΩ)

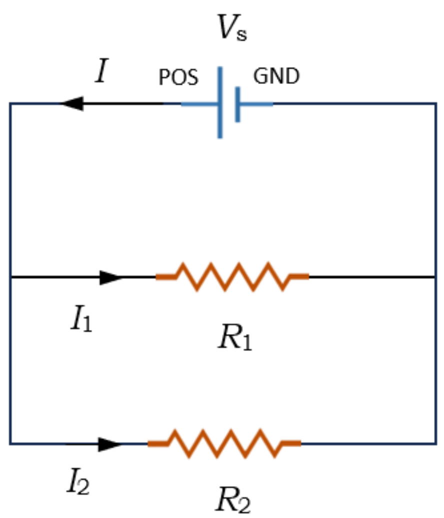

Table III: (Measured values)

R_1 = ……………….., R_2 =……………… $V_s = 4.0$ V

R_{eq} (Ω)	I (mA)	I_1 (mA)	I_2 (mA)	V_1 (V)	V_2 (V)

Table IV: (Calculated values): **using the measured values of R_1 & R_2**

R_{eq} (Ω)	I (mA)	I_1 (mA)	I_2 (mA)	V_1 (V)	V_2 (V)

1. Compare the measured values with the calculated ones.

   ……………………………………………………………………………………………

2. Using the measured values verify the relations for the voltage, current, and resistance given for the series circuit.

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Part Three: Combination of series & parallel resistors:
(coded values: R_1 = 560 Ω, R_2 = 390 Ω, R_3 = 1.0 kΩ)

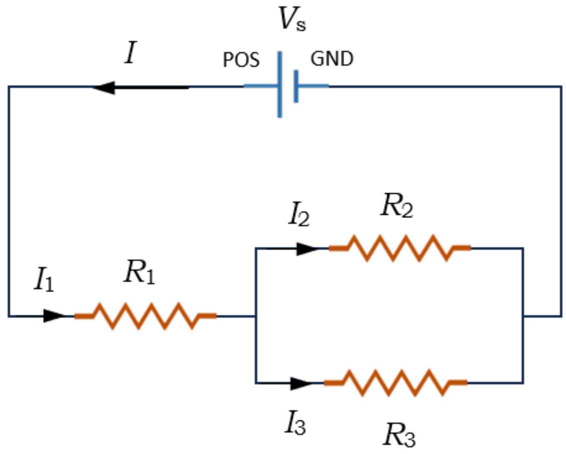

Table V: (Measured values)

R_1 = ..., R_2 =................., R_3 =.............. $\boldsymbol{V_s = 9.0}$ **V**

R_{eq} (Ω)	I (mA)	V_1 (V)	V_2 (V)	V_3 (V)

1. Calculate $R_{eq\,(2,3)}$: ....
2. Calculate R_{eq}: .... Is it equal to measured R_{eq}?..................
3. Calculate I: ....
4. Compare I calculated with I measured. ....
5. Compare V_2 with V_3. ....
6. Compare V_s with V_1 + V_{23}. ....

Discussion and conclusion

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Experiment Four: Kirchhoff’s Rules

Objectives

- To understand Kirchhoff’s loop and junction rules.
- To apply and verify Kirchhoff’s rules on a multi-loop circuit.

Introduction

Simple circuits can be analyzed using Ohm’s law and the rules for series and parallel combination of resistors. Very often it is not possible to reduce a complex circuit to a single loop. Therefore, to analyze complex circuits, we can use Kirchhoff’s rules for junctions and loops.

A **junction** is a point where three or more circuit elements meet. Looking at **Fig. 1**, we can identify two junctions: points ***b*** & ***e***. A **Loop** is any closed path in a circuit such that the start and the end points are the same. In **Fig. 1**, we can identify three loops: ***abefa***, ***bcdeb*** and ***acdfa.***

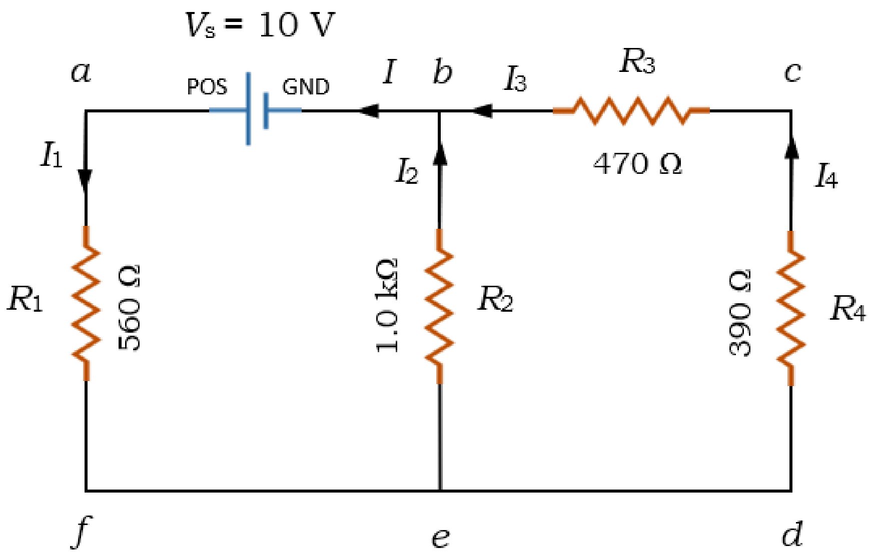

Fig. 1

Junction rule: the algebraic sum of all the currents entering and exiting any junction in a circuit equals zero. That is, at any junction:

$$\sum I = 0 \tag{1}$$

To apply the junction rule for a junction, use the following steps:

1. Consider the currents entering the junction positive, hence, those leaving the junction are considered negative, or vice versa.
2. Apply the junction rule (Eq.(1)).

Loop rule: the algebraic sum of all potential differences (ΔV) around any loop in a circuit equals zero. That is for any loop:

$$\sum \Delta V = 0 \tag{2}$$

To applying the loop rule, the following points should be considered:

1. Traverse a loop in one direction.
2. If a resistor is traversed in the direction of the current, then the potential difference across the resistor is $-RI$, otherwise it is $+RI$.
3. If a power supply V_s is traversed from $-ve$ to $+ve$ terminals (through the power supply), then the potential difference is $+V_s$, otherwise it is $-V_s$.

EXAMPLE: Consider **Fig. 1** (again) as shown to the right. To apply the loop rule to the loop ***bcdeb***, we *choose* to traverse the loop clockwise as shown in the figure. Hence, we get:

$-R_2I_2 + R_3I_3 + R_4I_4 = 0$

or (using ***V*** rather than ***RI***):

$-V_2 + V_3 + V_4 = 0$

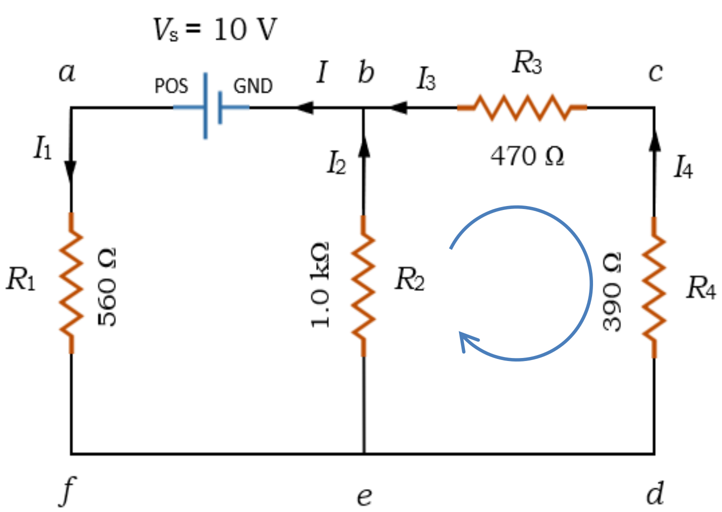

Fig. 1

Equipments

- ETW-3600 Analog Trainer
- Resistors: 390 Ω, 470 Ω, 560 Ω, 1000 Ω.
- Multimeter
- Wires.

Procedure

Circuit 1: (**mesuring currents**)

1. Using the resistors: R_1 = 560 Ω, R_2 = 1.0 kΩ, R_3 = 470 Ω, R_4 = 390 Ω, implement the circuit given in **Fig.1** as shown in **Fig. 2**.
2. Disconnect the POS & GND connectors from the circuit and measure the equivalent resistance R_{eq}. Record the value in **Table I**.
3. Reconnect the POS & GND connectors to the circuit.
4. Measure the current through each resistor as I_1, I_2, I_3, and I_4, and measure the current I delivered by the power supply. Record in **Table I**.

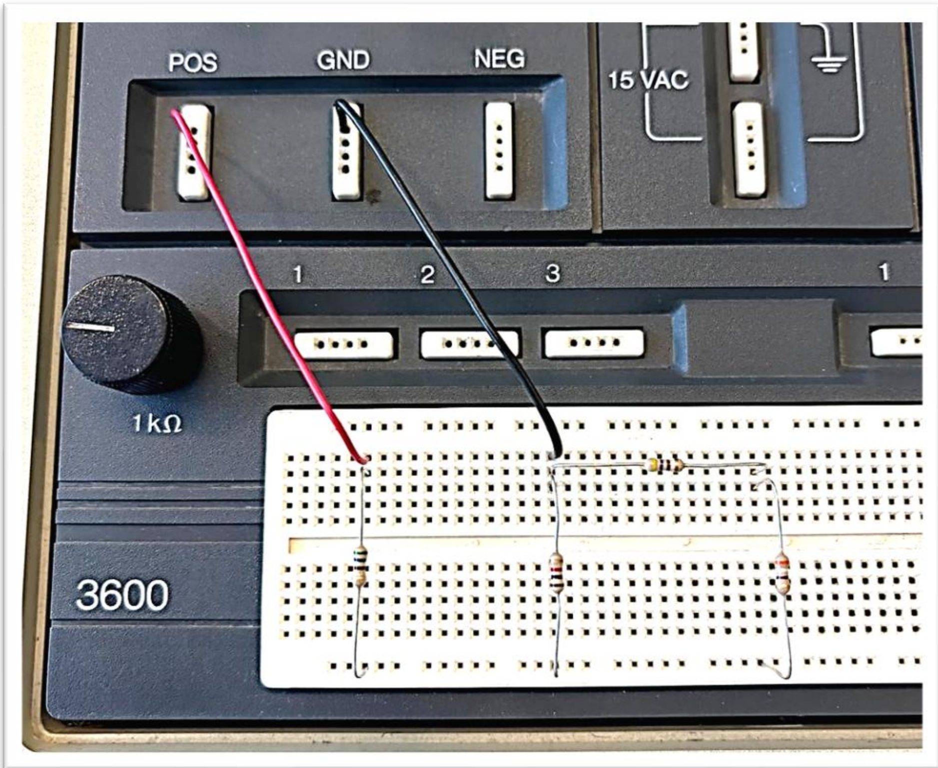

Fig. 2

Circuit 2: (**measuring voltages**)

1. Using the resistors: R_1 = 560 Ω, R_2 = 1.0 kΩ , R_3 = 470 Ω, implement the circuit given in **Fig. 3** as shown in **Fig. 4**.
2. Measure the voltages across each resistor as V_1, V_2, and V_3. Record the values in **Table II**. (<u>connect the red probe to +*ve* side of the resistor</u>)

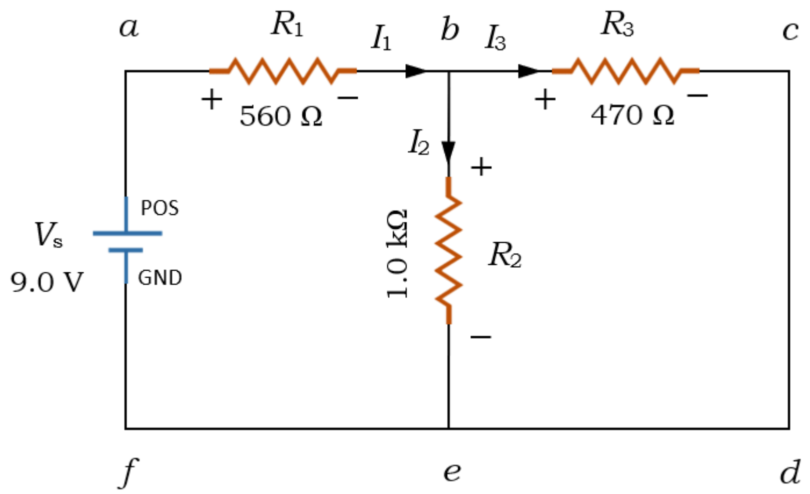

Fig. 3

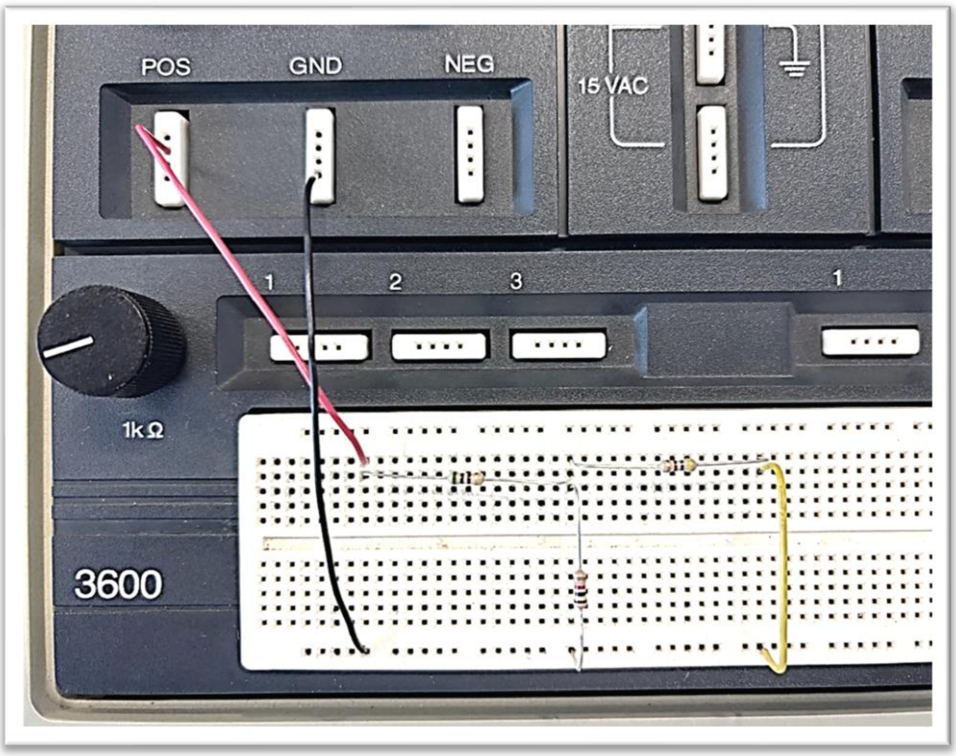

Fig. 4

Section: ……………………

Date:………………………..

جامعة الكويت
KUWAIT UNIVERSITY

Exp. No. (4)

KIRCHOFF'S RULES

Student name:………………………………………….

Student ID:…………………………………………..

Instructor name:……………………………………..

Group no.:

Objectives

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Data and analysis of results

Circuit 1: **Mesuring currents**

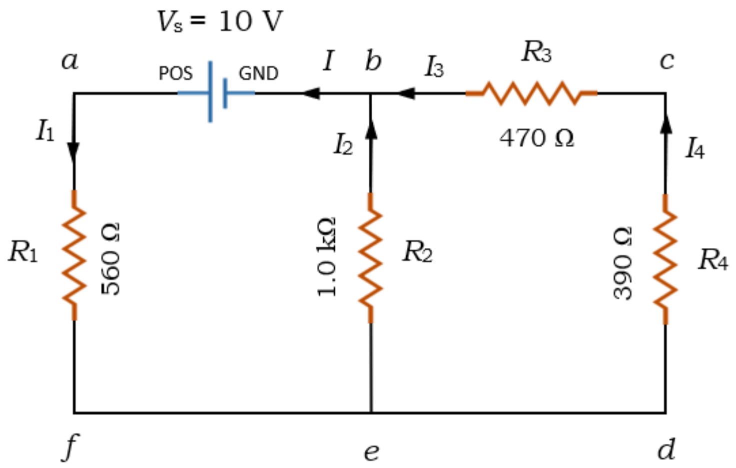


Fig. 1

Table I

R_{eq} (Ω)	I (mA)	I_1 (mA)	I_2 (mA)	I_3 (mA)	I_4 (mA)

1. Verify the **junction rule** for junctions ***b*** and ***e***:

- For junction ***b***: ....

- For junction ***e***: ....

  Is the junction rule verified?..

2. Verify the **loop rule** for the loops ***abefa*** and ***acdfa***:

- For the loop ***abefa***: ....

- For the loop ***acdfa***: ....

  Is the loop rule verified? ....

Circuit 2: **Measuring voltages**

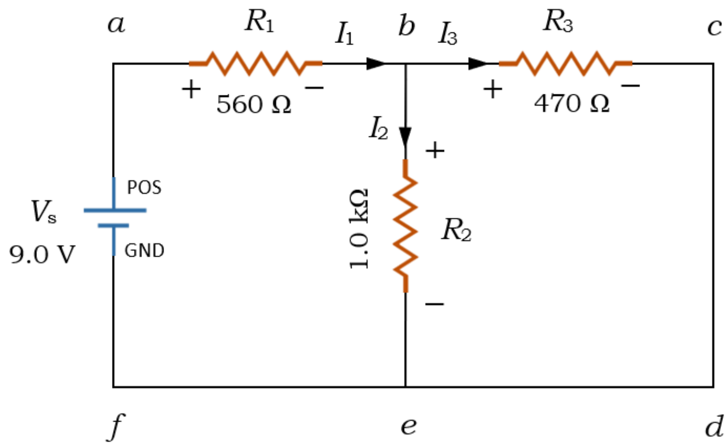


Fig. 3

(connect the red probe to +ve side of the resistor to measure the voltage)

Table II:

V_1 (V)	V_2 (V)	V_3 (V)

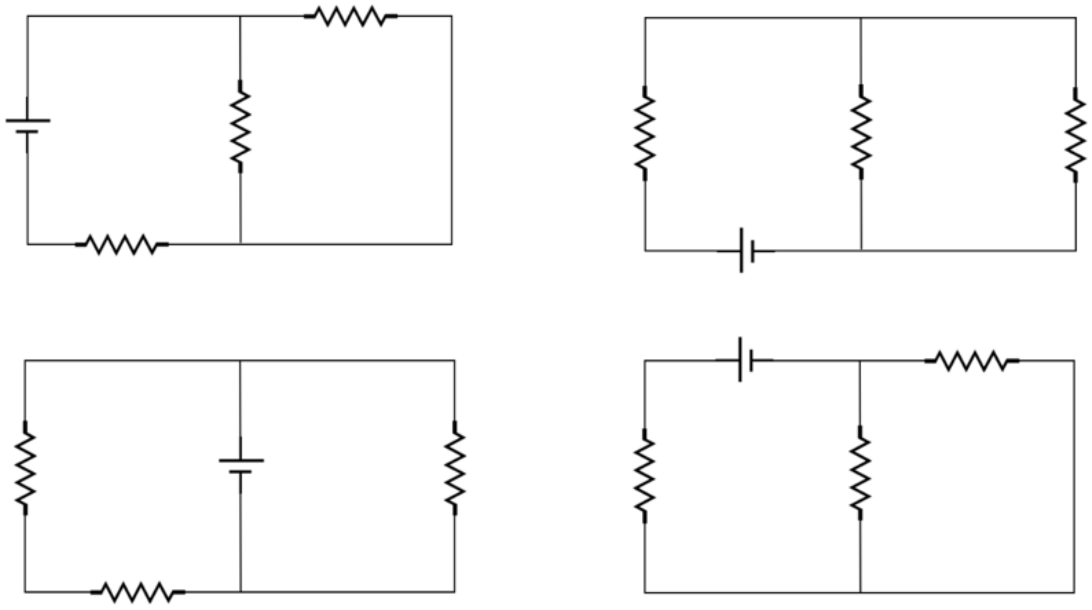
Verify the loop rule for the loops ***abefa*** and ***acdfa*** (**using voltage values)**:

- For the loop ***abefa***: ....
- For the loop ***acdfa***: ....

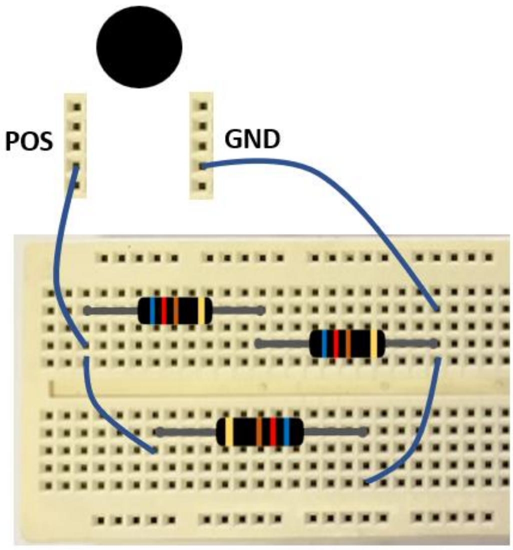
Is the loop rule verified? ....

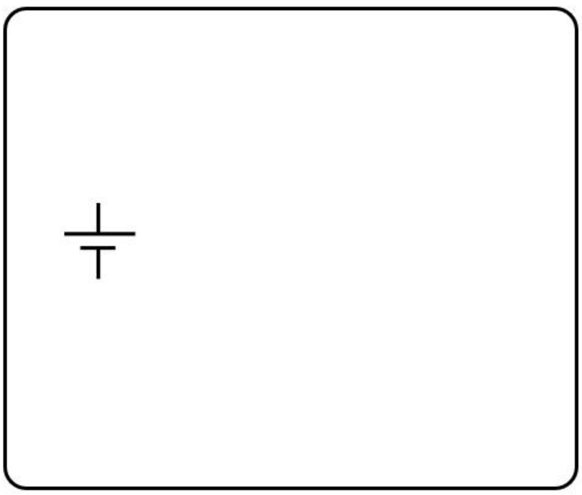
Questions

Q1. The resistors in the circuits below are identical. Three out of the four circuits are equivalent to each other, but one is different. Mark the different circuit with a ✓ sign.



Q2. Draw a schematic diagram for the circuit given below in the box to the right starting from the power supply symbol.





Discussion and conclusion

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Experiment Five: Charging a Capacitor

Objectives

- To analyze the process of charging a capacitor.
- To determine the time constant of an R-C circuit.

Introduction

A capacitor (C) is an electronic device that stores electric charges and hence, it stores electrical potential energy. A capacitor consists of two conductors separated by insulator. When the capacitor is charged to charge Q, one of the conductors becomes positively charged (with charge $+Q$) and the other becomes negatively charged (with charge $-Q$); and only the positive charge $+Q$ (or just Q) represents the charge of the capacitor. When the capacitor carries a charge Q, a potential difference V is developed across its leads, where $C = Q/V$ is the capacitance of the capacitor. The SI unit of C is Farad (F).

In this experiment we will use a cylindrical capacitor to analyze the process of charging a capacitor. Consider a single loop circuit as shown in **Fig. 1** where a capacitor C is connected in series to a resistor R and to an electromotive force (power supply) $\mathcal{E}$. Capacitor C is initially uncharged. By closing the switch S, a current (I) is set up in the loop and the capacitor begins to charge (**Fig. 2**).

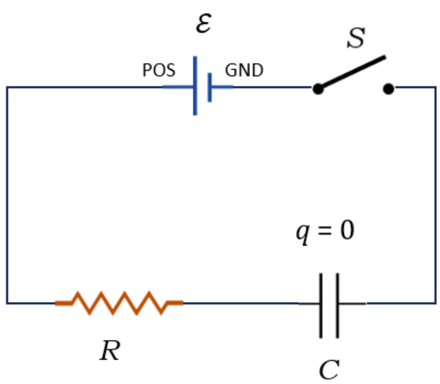

Fig. 1

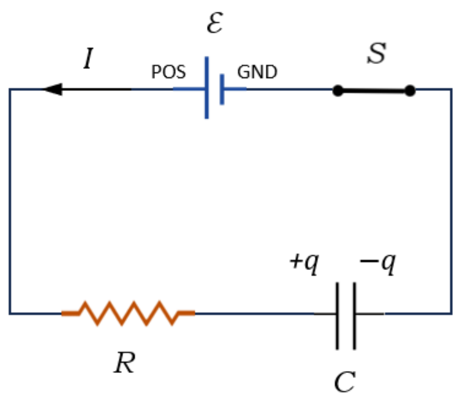

Fig. 2

As the capacitor charges up, its voltage increases exponentially according to the formula

$$V_c = \mathcal{E}\left(1 - e^{-\frac{t}{\tau}}\right) \tag{1}$$

where $\tau = RC$ is the time constant of the R-C circuit. The time constant is a measure of how fast the capacitor can be charged, since if τ is big, then the capacitor is charged slowly, whereas if it is small, the capacitor charges faster.

At a time $t = \tau$, the voltage across the capacitor

$$V_c = \mathcal{E}(1 - e^{-1}) = 0.63\mathcal{E} \tag{2}$$

Therefore, by plotting a graph of V_c versus t, the time constant τ can be determined as shown in **Fig. 3**. If R is given, the capacitance C can be determined.

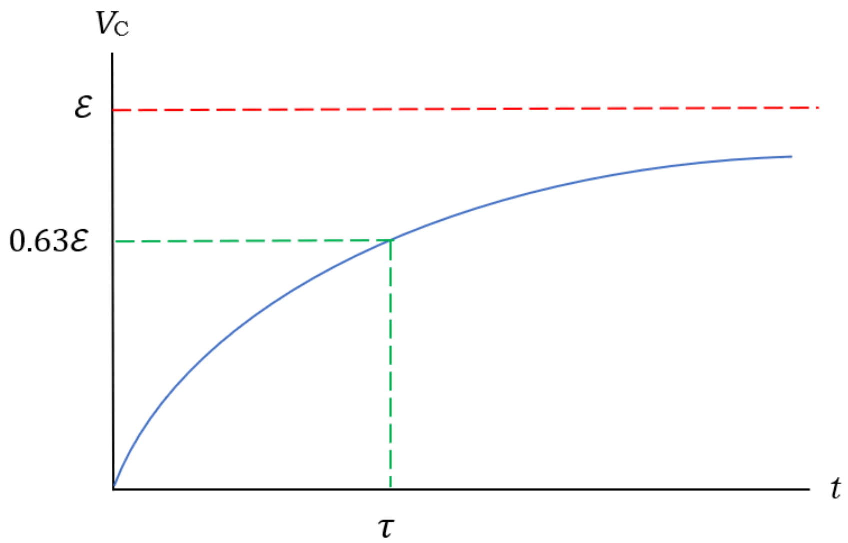

Figure 3: Graph of V_c versus t for the charging process

Equipments

- ETW-3600 Analog Trainer
- 220 kΩ Resistors and 470 μF Capacitor
- Multimeter, Stopwatch
- Wires.

Procedure

1. Connect the circuit given in **Fig. 1** as shown in **Fig. 4** (make sure that the negative lead of the capacitor is connected to the ground).
2. Set the power supply voltage to $\mathbf{12.0\ V}$. Disconnect the POS terminal.
3. Short out the capacitor temporarily by connecting a wire parallel to it.
4. Connect the POS terminal and start the stopwatch simultaneously.
5. For each value of V_c given in **Table I**, pause the display of the stopwatch, record the time (**min:sec**) as t_1 in the table, then resume the stopwatch.
6. Stop the stopwatch.
7. Repeat the steps 2-6 one more time and record the time (**min:sec**) as t_2.
8. Convert (min:sec) to (s) then calculate the average time t_{avg} and record it in the table.
9. Plot a graph of V_c versus t_{avg}, from which determine the time constant τ.
10. Calculate C using the time constant.

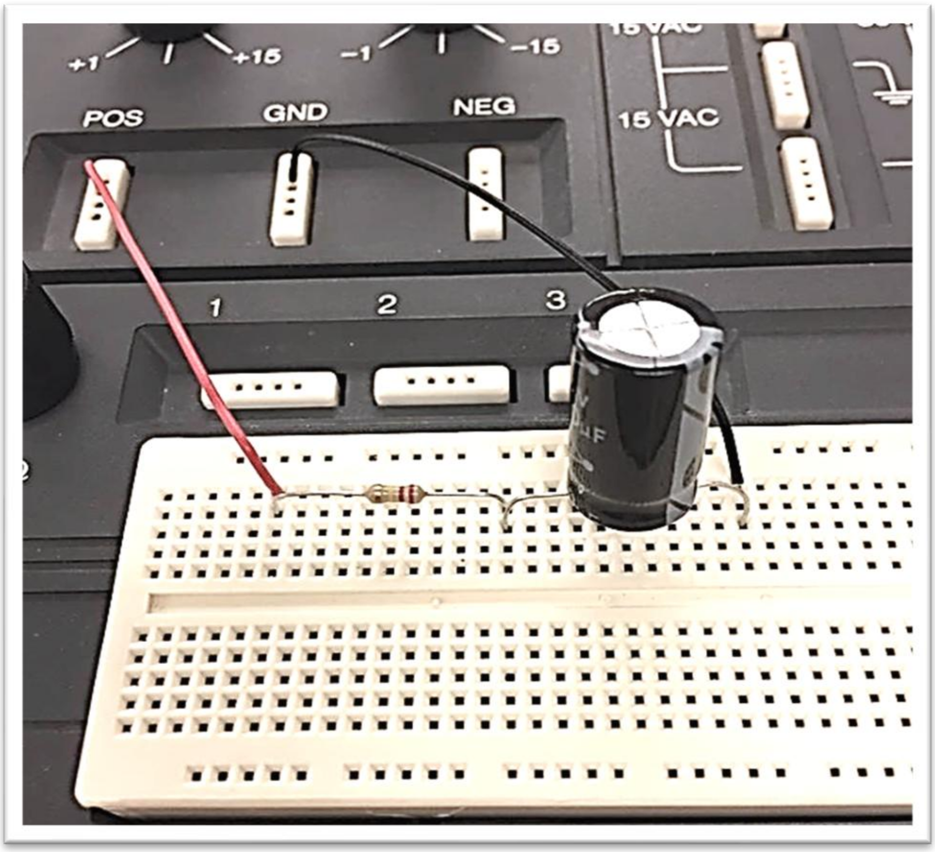

Fig. 4: *R*-*C* charging circuit connection

Section: ....

Date:..........................

جامعة الكويت
KUWAIT UNIVERSITY

Exp. No. (5)

CAPACITOR CHARGING

Student name:..

Student ID:..

Instructor name:..

Group no.:

Objectives

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………

Data and analysis of results

Table I **(V_s = 12 V)**

V_c (V)	t_1 (min:sec)	t_2 (min:sec)	t_1 (s)	t_2 (s)	t_{avg} (s)
0	0	0	0	0	0
2.0					
4.0					
5.0					
6.0					
7.0					
8.0					
9.0					
10.0					

- Time constant determined from the graph: τ = ……………………….
- Capacitance obtained from the graph: C_{meas} =……………………….
- Percentage error in C value:

$$\left|\frac{C_{meas}-C_{given}}{C_{given}}\right| \times 100 = \ldots\ldots\ldots\ldots\ldots\%$$

Questions

1- What is the function of capacitors in electrical circuitry?

....

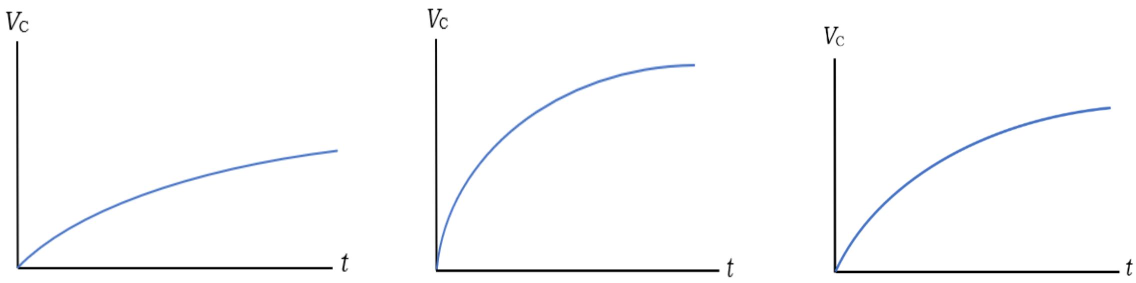
2- A capacitor carries only one type of charge, whether positive or negative. (True or False)?........................

3- In this experiment, if the electromotive force ($\mathcal{E}$) is set to greater value, then the capacitor is charged fast. (True or False)? ....

4- If the time constant is small, the capacitor is charged fast.

(True or False)?......................

5- Which of the following graphs shows that a capacitor is charging faster? (assume same $\mathcal{E}$, and same graph scale)



(a) (b) (c)

Discussion and conclusion

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Experiment Six: Capacitor discharging

Objectives

- To analyze the process of discharging a capacitor.
- To determine the time constant of an R-C circuit.

Introduction

In experiment five, we analyzed the process of charging a capacitor. Here, we will analyze the process of discharging a capacitor. Consider the circuit shown in **Fig. 1**, where a capacitor C is connected in parallel to a resistor R and to an electromotive force (power supply) $\mathcal{E}$. Initially, when the switch S is closed, the capacitor is fully charged to a value of $Q = C\mathcal{E}$. As the switch is opened (**Fig. 2**), the power supply is disconnected from the circuit and the capacitor starts to discharge through the resistor.

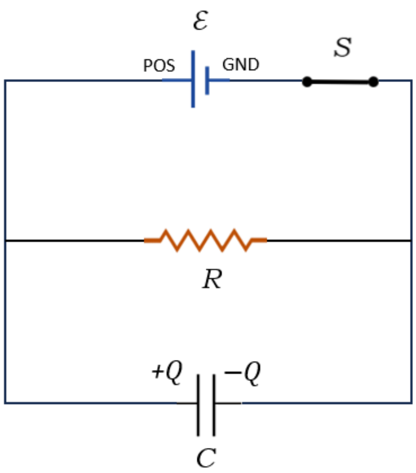

Fig. 1

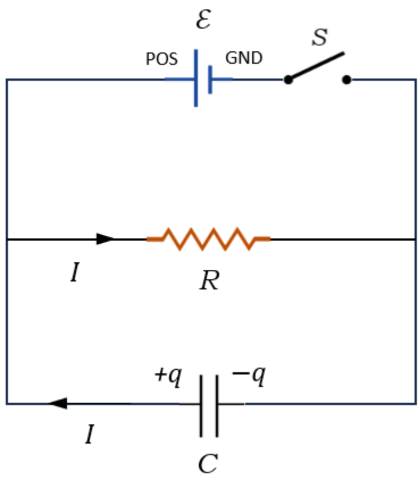

Fig. 2

As the capacitor discharges, its voltage decreases exponentially according to the formula

$$V_c = \mathcal{E}e^{-\frac{t}{\tau}} \tag{1}$$

where $\tau = RC$ is the time constant of the R-C circuit. The time constant is a measure of how fast the capacitor discharges, since if τ is big, then the capacitor discharges slowly, whereas if it is small, the capacitor discharges faster.

At a time $t = \tau$, the voltage across the capacitor

$$V_c = \mathcal{E}e^{-1} = 0.37\mathcal{E} \tag{2}$$

Therefore, by plotting a graph of V_c versus t, the time constant τ can be determined as shown in **Fig. 3**. If R is given, the capacitance C can be determined.

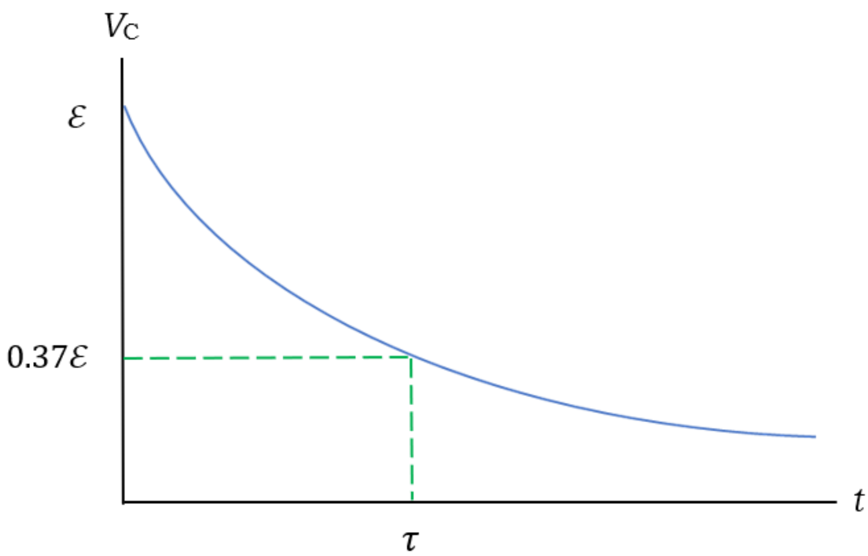

Fig. 3: A plot of V_c versus t for the discharging processes

Equipments

- ETW-3600 Analog Trainer
- 220 kΩ Resistor and 470 μF Capacitor
- Multimeter, Stopwatch
- Wires.

Procedure

1. Connect the circuit given in **Fig. 1** as shown in **Fig. 4** (make sure that the lead of the capacitor at the arrowhead is connected to the ground).
2. Turn on the power supply and set the voltage to **12.0 V**. The capacitor will charge up immediately to $V_c = \mathcal{E}$.
3. Disconnect the POS terminal and start the stopwatch simultaneously.
4. For each value of V_c given in **Table I**, pause the display of the stopwatch, record the time (**min:sec**) as t_1, then remove the pause of the stopwatch.
5. Stop the stopwatch and reconnect the POS terminal.
6. Repeat steps 3-5 one more time and record the time (**min:sec**) as t_2.
7. Convert (min:sec) to (s) then calculate t_{avg} and record it in the table.
8. Plot a graph of V_c versus t_{avg}, from which determine the time constant τ.

10. Calculate C using the time constant.

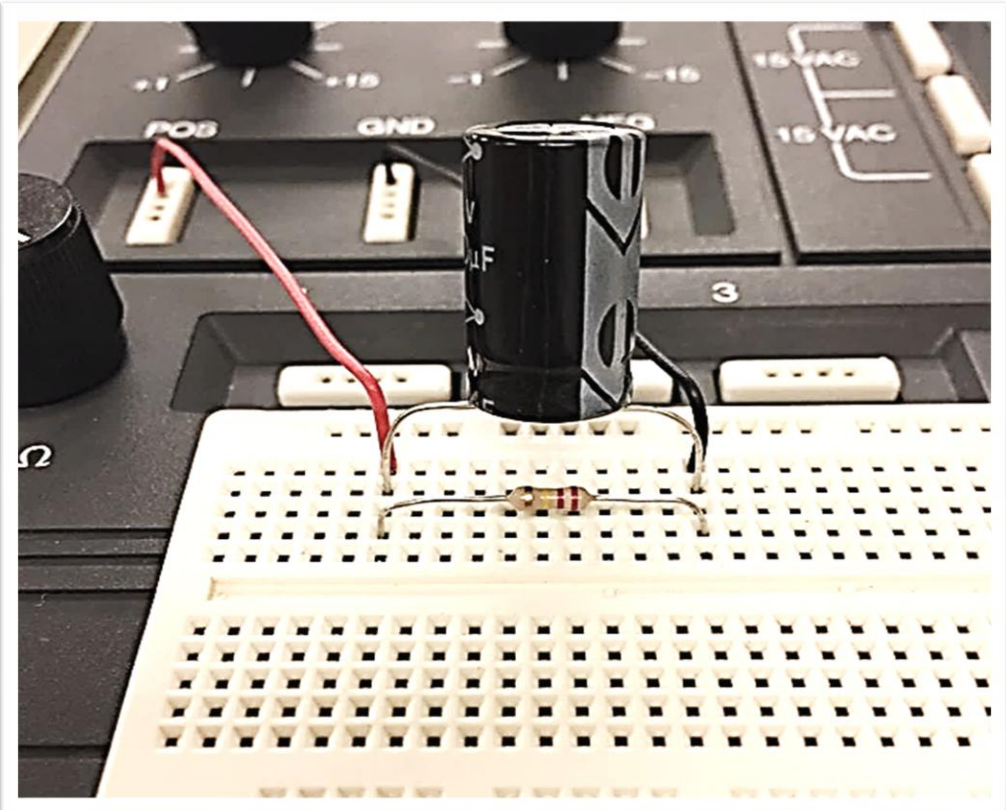

Fig. 4: *R*-*C* discharging circuit connection

Section: ....

Date:...........................

جامعة الكويت
KUWAIT UNIVERSITY

Exp. No. (6)

DISCHARGING A CAPACITOR

Student name:..

Student ID:...

Instructor name:..

Group no.:

Objectives

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Data and analysis of results

Table I **(V_s = 12 V)**

V_c (V)	t_1 (min:sec)	t_2 (min:sec)	t_1 (s)	t_2 (s)	t_{avg} (s)
12.0	0	0	0	0	0
10.0					
8.0					
7.0					
6.0					
5.0					
4.0					
3.0					
2.0					

- Time constant determined from the graph: τ = ………………………
- Capacitance obtained from the graph: C_{meas} =………………………
- Percentage error in C value:

$$\left|\frac{C_{meas}-C_{given}}{C_{given}}\right| \times 100 = \ldots\ldots\ldots\ldots\ldots\%$$

Questions

1. If a resistor of double value is used, what is the value of a capacitor to be used to keep the time constant the same?

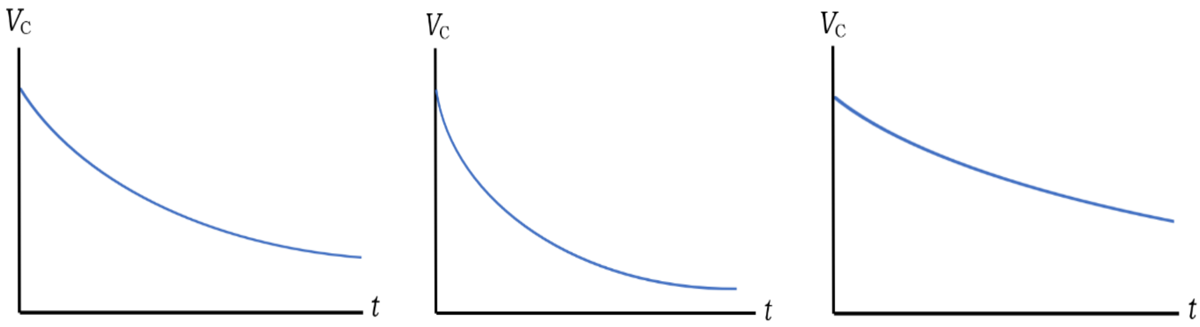
   ……………………………………………………………………………………………

2. In this experiment, if the electromotive force ($\mathcal{E}$) is set to smaller value, then the capacitor would need shorter time to discharge to $V_c = 0.37\mathcal{E}$ value. (True or False)?…………………

3. If the time constant is big, the capacitor discharges slowly.

   (True or False)?…………………

4. Which of the following graphs shows that a capacitor is discharging slowly? (assume same $\mathcal{E}$, and same graph scale)



(a) (b) (c)

Discussion and conclusion

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Experiment Seven
Series & Parallel Capacitors

Objectives

- To determine the equivalent capacitance of series and parallel networks of capacitors.
- To verify the relations for the charges, voltages, and capacitances for capacitors network.

Introduction

A capacitor (C) is an electronic device that stores electric charges and hence, it stores electrical potential energy. A capacitor consists of two conductors separated by insulator. When the capacitor is charged to charge Q, one of the conductors becomes positively charged (with charge $+Q$) and the other becomes negatively charged (with charge $-Q$); and only the positive charge $+Q$ (or just Q) represents the charge of the capacitor. When the capacitor carries a charge Q, a potential difference V is developed across its leads, where $C = Q/V$ is the capacitance of the capacitor. The SI unit of C is Farad (F).

Capacitors in series: when two capacitors are connected in series to a power supply V_s (**Fig.1**), the charge on each capacitor would be the same:

$$Q = Q_1 = Q_2 \tag{1}$$

where Q is the charge delivered by the power source, Q_1 and Q_2 are the charges on each individual capacitor.

The potential difference V_s applied across the network of series capacitors is equal to the sum of the potential differences across the two capacitors:

$$V_s = V_1 + V_2 \tag{2}$$

Using Eq.(2) and the relation $C = Q/V$, it can easily be proved that the equivalent capacitance (C_{eq}) of the network is given by

$$\frac{1}{C_{\mathrm{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} \tag{3}$$

Based on Eq.(3), *the equivalent capacitance for two capacitors connected in series is less than the smallest one*.

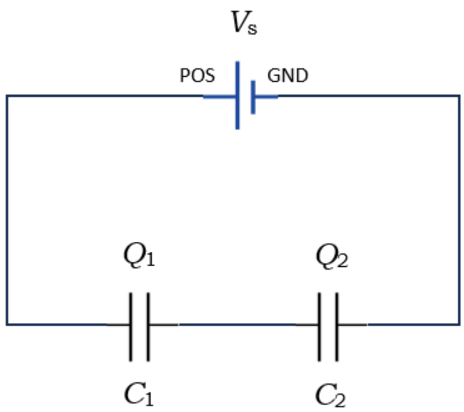

Fig. 1: two capacitors in series

Capacitors in Parallel: when two capacitors are connected in parallel to each other and to a power supply V_s (**Fig.2**), the potential difference across each capacitor would be the same:

$$V_s = V_1 = V_2 \tag{4}$$

and the charge Q delivered by the power supply would equal the sum of charges on each individual capacitor, i.e.,

$$Q = Q_1 + Q_2 \tag{5}$$

Using Eq.(5) and the relation $C = Q/V$, it can easily be proved that the equivalent capacitance for the combination of parallel capacitors:

$$C_{\mathrm{eq}} = C_1 + C_2 \tag{6}$$

Based on Eq.(6), *the equivalent capacitance for two capacitors connected in parallel is greater than the greatest one*.

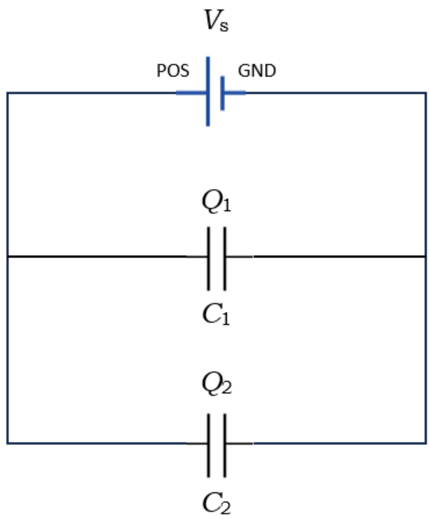

Fig. 2: Two capacitors in parallel

To determine the equivalent capacitance for both series & parallel circuits, we utilize the process of discharging a capacitor through a resistor (that was studied in Exp. (6)). Therefore, a resistor is first connected in parallel to the circuits, as shown in **Figs.3 & 4**, then by measuring the time (t) needed for the voltage across the capacitors network to drop to a certain value (V_{Ceq}), and using the formula $V_{\mathrm{Ceq}} = \mathcal{E}e^{-\frac{t}{\tau}}$ (where $\mathcal{E} = V_s$), the time constant τ, and hence, C_{eq} can be determined.

Equipments

- ETW-3600 Analog Trainer
- 330 kΩ Resistor, 330 μF and 470 μF Capacitors
- Multimeter, Stopwatch
- Wires.

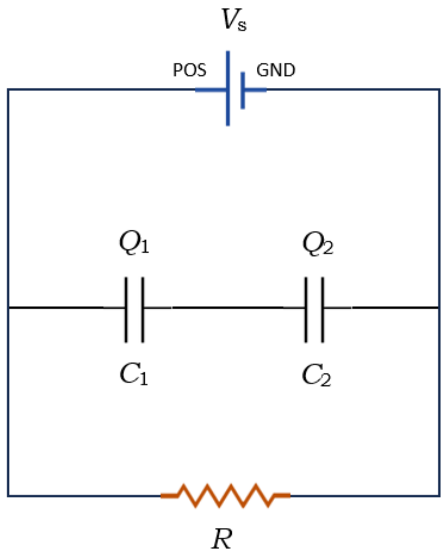

Fig. 3: Discharging circuit for the series capacitors network

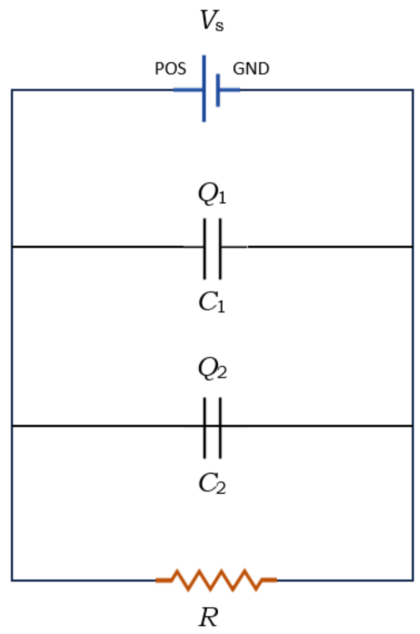

Fig. 4: Discharging circuit for the parallel capacitors network

Procedure:

Part One: **Capacitors in series:** ($C_1 = 470$ μF, $C_2 = 330$ μF, $R = 330$ kΩ)

1. Measure the value of the resistor using DMM and record it in **Table I**.
2. **Short out each capacitor (let positive lead touch the negative lead).**
3. Connect the circuit given in **Fig.3** as shown in **Fig.5.** (**<u>make sure that the negative leads of the capacitors are connected to the right as shown</u>**).
4. Set the power supply voltage to **10.0 V**.
5. Connect a DMM across the resistor (which reads the same voltage as for the capacitor network (V_{Ceq})).
6. Disconnect the wire from the POS connector and start the stopwatch simultaneously.
7. Stop the stopwatch when DMM reads **5.0 V**, and record the time as t_1 in **Table I**, then reconnect the wire to the POS connector.

8. Repeat steps 6 & 7 two more times, record times as t_2, and t_3 in **Table I**, and calculate t_{avg}.
9. Find τ using $V_{\text{Ceq}} = V_s e^{-\frac{t_{\text{avg}}}{\tau}}$ then calculate C_{eq} and record in **Table I**.
10. **Remove the resistor** from the circuit, then measure V_1 & V_2 and record values in **Table II**.

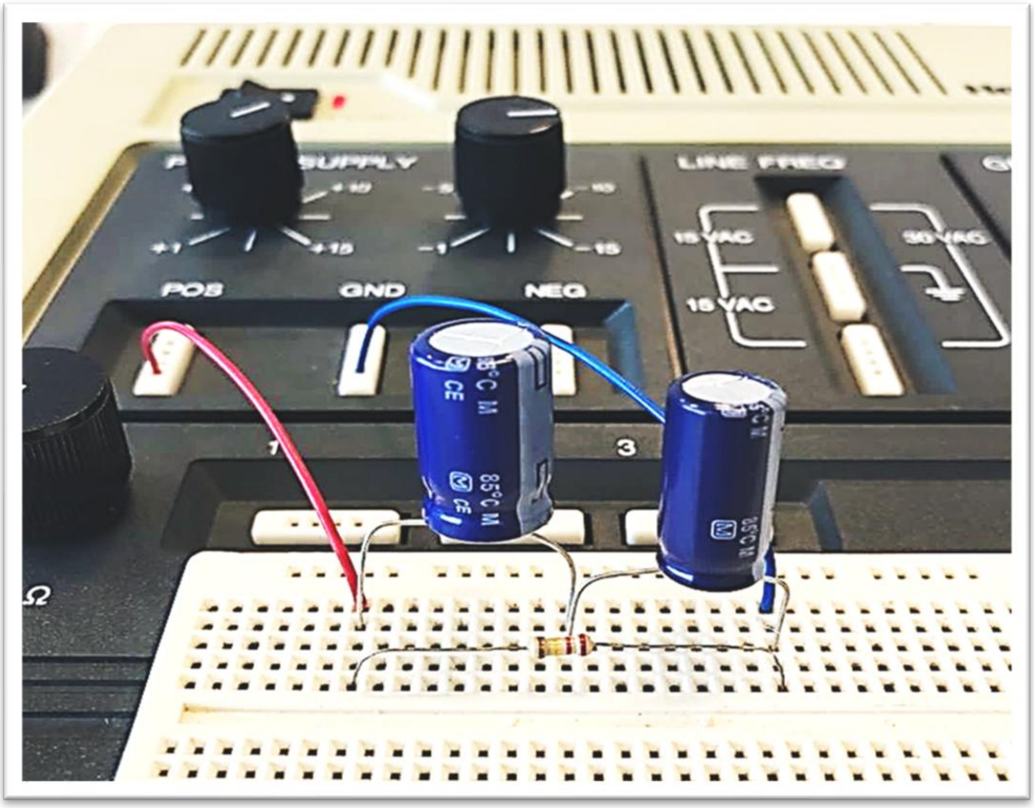

Fig.5: Capacitors in series

Part Two: **Capacitors in parallel:** (C_1 = 470 μF, C_2 = 330 μF, R = 330 kΩ)

1. Record the value of the same resistor you measured, in **Table III**.
2. Connect the circuit given in **Fig.4** as shown in **Fig.6**. (**<u>make sure that the negative leads of the capacitors are connected to the right as shown</u>**).
3. Set the power supply voltage to **10.0 V**.
4. Connect a DMM across the resistor (which reads the same voltage as for the capacitor network (V_{Ceq})).

5. Disconnect the wire from the POS connector and start the stopwatch simultaneously.

6. Stop the stopwatch when DMM reads **8.5 V** and record the time as t_1 in **Table III**, then reconnect the wire to the POS connector.

7. Repeat steps 5 & 6 two more times, record the times as t_2, and t_3 in **Table III**, and calculate t_{avg}.

8. Find τ using $V_{\mathrm{Ceq}} = V_s e^{-\frac{t_{\mathrm{avg}}}{\tau}}$ then calculate C_{eq} and record in **Table III**.

9. **Remove the resistor** from the circuit, then measure V_1 & V_2 and record values in **Table IV**.

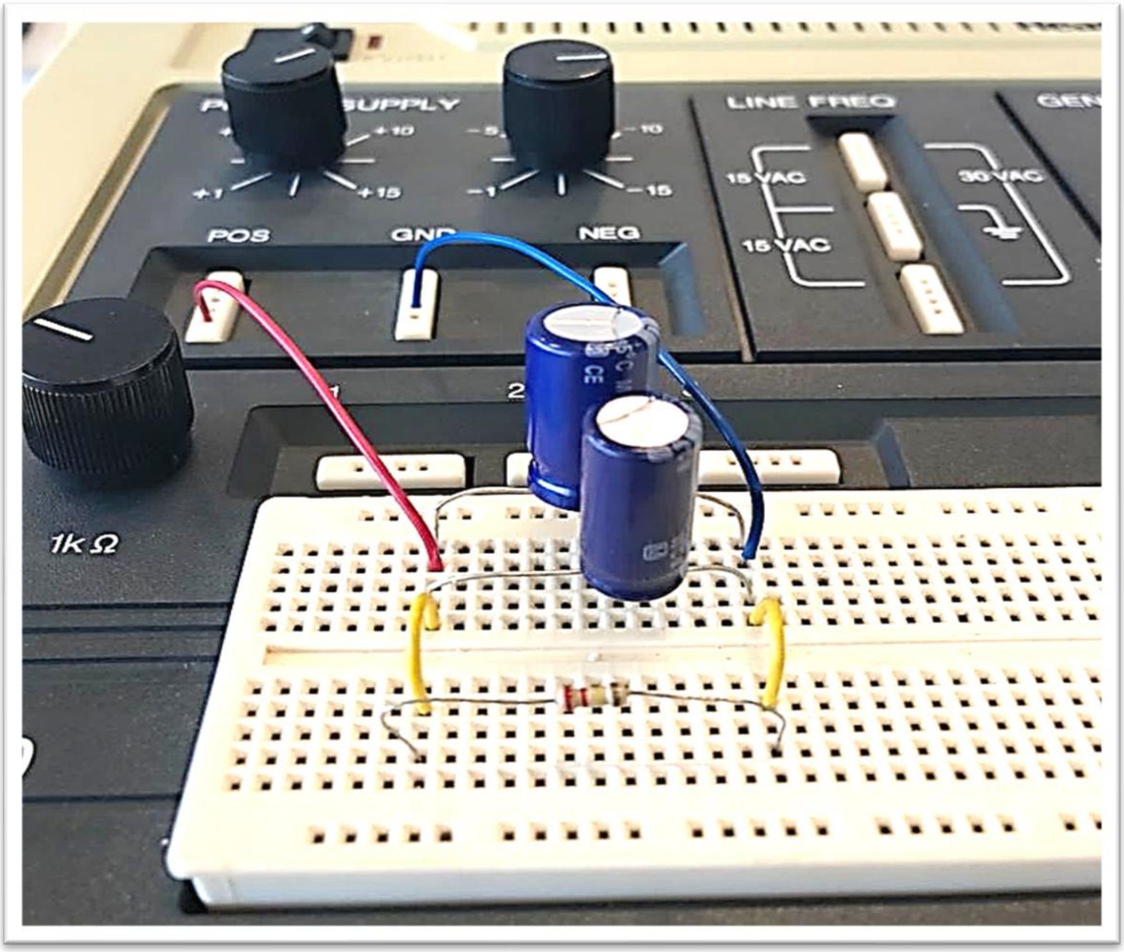

Fig.6: Capacitors in parallel

Section: ....

Date:..............................

جامعة الكويت
KUWAIT UNIVERSITY

Exp. No. (7)

SERIES & PARALLEL CAPACITORS

Student name:..

Student ID:..

Instructor name:..

Group no.:

Objectives

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....

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Data and analysis of results

Part One: **Capacitors in series: (Note:** Discharge to $\boldsymbol{V_{\mathrm{Ceq}} = 5.0\ \mathrm{V}}$)

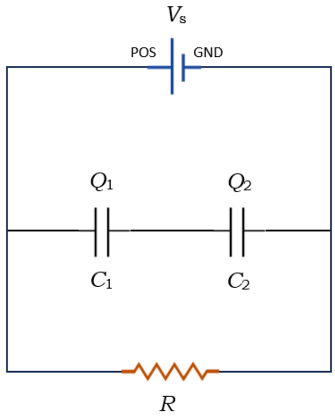


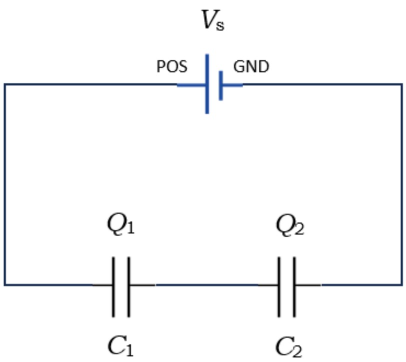
Table I: ($C_1 = 470\ \mu$F, $C_2 = 330\ \mu$F, $R = 330$ kΩ) $\boldsymbol{V_s = 10\ \mathrm{V}}$

R_{meas} (kΩ)	t_1 (s)	t_2 (s)	t_3 (s)	t_{avg} (s)	τ (s)	C_{eq} (μF)

- **Remove the resistor** from the circuit

Table II

V_1 (V)	V_2 (V)



- Calculate C_{eq} using Eq. (3): C_{eq} =.................
- Compare C_{eq} from the table to that calculated using Eq. (3)

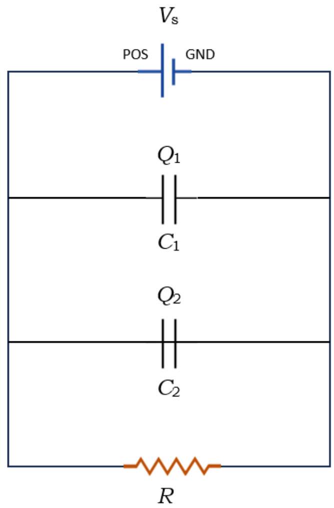
  ....

- Compare $(V_1 + V_2)$ to V_s ....
- Calculate $Q_1 = C_1V_1$ =........... mC, $Q_2 = C_2V_2$ =.............. mC, and $Q_{eq} = C_{eq}V_s$ =........... mC
- Compare Q_1, Q_2, Q_{eq}...

Part Two: **Capacitors in parallel:** (**Note:** Discharge to $V_{\mathbf{Ceq}} = \mathbf{8.5\ V}$)

Table III: ($C_1 = 470\ \mu\text{F}$, $C_2 = 330\ \mu\text{F}$, $R = 330\ \text{k}\Omega$) $\boldsymbol{V_s} = \mathbf{10}$

R_{meas} (kΩ)	t_1 (s)	t_2 (s)	t_3 (s)	t_{avg} (s)	τ (s)	C_{eq} (μF)



- **Remove the resistor** from the circuit

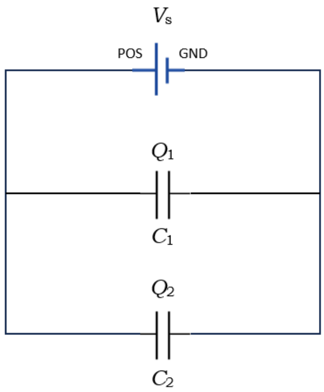


Table IV

V_1 (V)	V_2 (V)

- Calculate C_{eq} using Eq. (6): C_{eq} =....................................
- Compare C_{eq} from the table to that calculated using Eq. (6)

  ....
- Compare V_1, V_2, and V_s ....
- Calculate $Q_1 = C_1V_1$ =.................. mC, $Q_2 = C_2V_2$ =................... mC,

  and $Q_{eq} = C_{eq}V_s$ =................ mC
- Compare $(Q_1 + Q_2)$ to Q_{eq}...

Questions

1. Capacitors store magnetic energy. True or False?...............................
2. For two capacitors connected in parallel, $Q = Q_1 = Q_2$. True or False? ....
3. For two capacitors connected in series, $V_s = V_1 + V_2$. True or False? ....
4. The equivalent capacitance for two capacitors connected in parallel is greater than the greatest one. True or False?...............................

Discussion and conclusion

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Experiment Eight

Electron Charge to Mass Ratio (e/m)

Objectives

- To study the effect of magnetic field on a moving charged particle.
- To determine the electronic charge to mass ratio (e/m).

Introduction

An electron ($q = -e$) moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$ (**Fig.** 1) experiences a magnetic force that is given by

$$\vec{F}_m = q\vec{v} \times \vec{B} \tag{1}$$

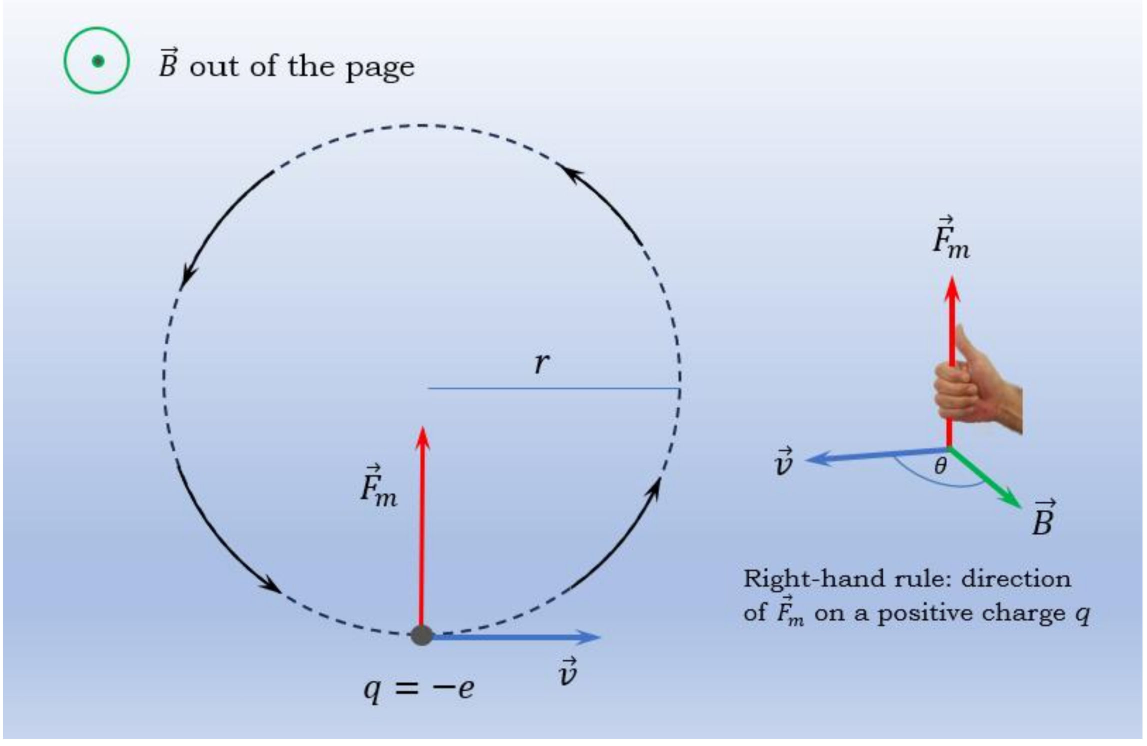


Fig. 1: Magnetic force on an electron moving in a magnetic field

where the direction of $\vec{F}_m$, which is determined according to the right-hand rule, is at right angle to both $\vec{v}$ and $\vec{B}$, and points up (since $q = -e$).

If $\vec{v} \perp \vec{B}$, then the electron moves in a circular path with radius r, where $\vec{F}_m$ forms the centripetal force, and by applying Newton's second law we get

$$evB = m\frac{v^2}{r} \tag{2}$$

The PASCO Model SE-9638 e/m apparatus (**Fig. 2**) provides a simple method (like that used by J.J. Thomson in 1897) for measuring e/m ratio. It consists mainly of a pair of Helmholtz coils, a glass tube, an electron gun, a mirrored scale, and control unit.

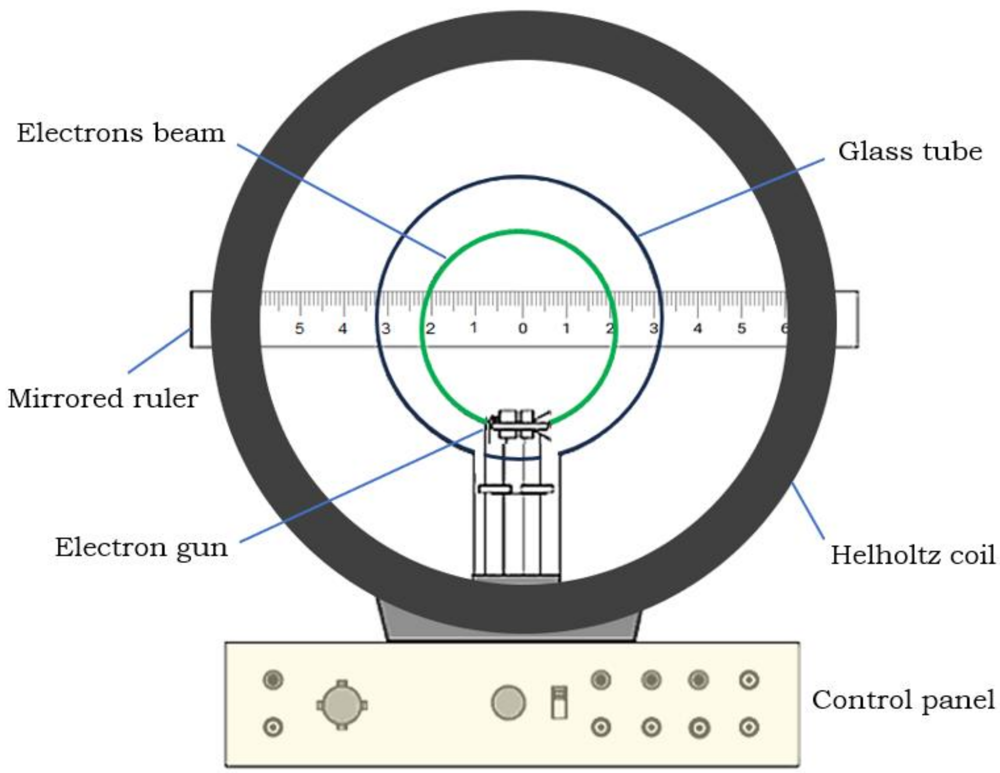


Fig. 2: e/m apparatus

When a current is set up through the Helmholtz coils, a magnetic field $\vec{B}$ is produced near the axis of the pair of coils at right angle to the plane of the coils. The magnitude of the magnetic field is given by $B = 7.8 \times 10^{-4}\, I,$ where I is the current in the Helmholtz coils.

Figure 3 shows a schematic diagram of the Electron gun. When the Cathode gets heated by the heater element, electrons are released from it. Applying a potential difference between the electrodes (V_{elec}) the electrons are accelerated toward the Anode, and part of them emerge through the hole that is in the Anode forming a beam of electrons. As electrons exit the electron gun, they gain kinetic energies given by $\frac{1}{2}mv^2 = eV_{elec}$ (based on the conservation of mechanical energy). Therefore, the speed of the electrons

$$v = \left(\frac{2eV_{elec}}{m}\right)^{1/2} \tag{3}$$

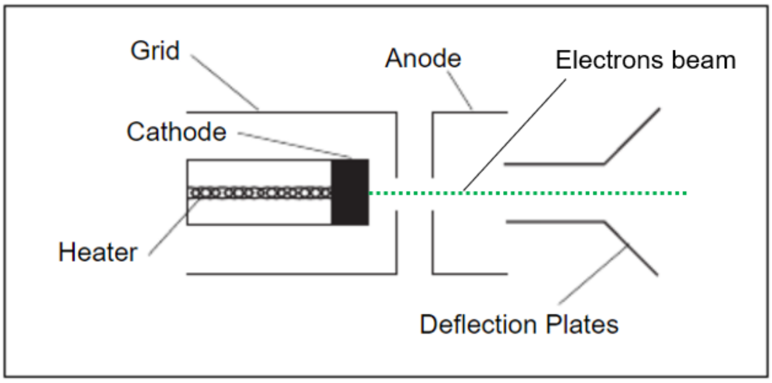


Fig. 3: Electron gun

Substituting for v (Eq.(3)) into Eq.(2), we get a formula for e/m:

$$\frac{e}{m} = \frac{2V_{elec}}{B^2 r^2} \tag{4}$$

which can be rearranged as

$$V_{elec} = \frac{e}{m}\frac{B^2}{2}r^2 \tag{5}$$

Equation (5) shows that V_{elec} is directly proportional to r^2.

In this experiment, setting the current through the Helmholtz coils to a specific value, then by varying V_{elec}, the radius r of the electrons beam circular path varies. A plot of V_{elec} versus r^2 should result in a straight line where e/m can be determined from the slope.

If the direction of the velocity of the electron $\vec{v}$ was other than at right angle to the magnetic field $\vec{B}$, then the electrons beam will take a helical path (due to the component of $\vec{v}$ that is parallel to the magnetic field).

Equipments:

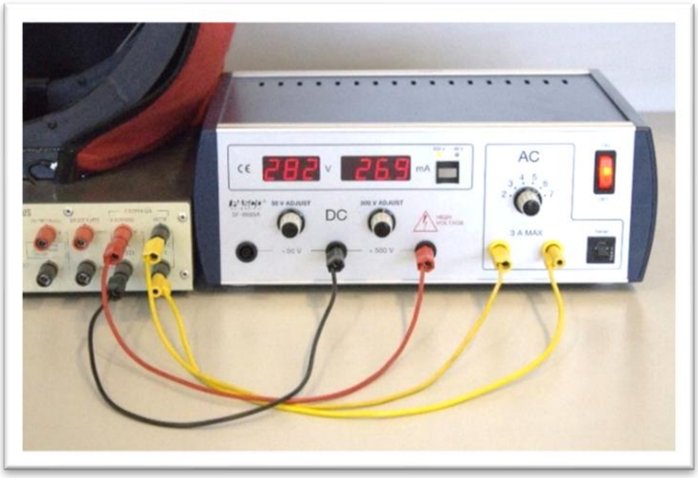
- UCHIDA Experimental Apparatus for e/m measurement.
- PASCO Low Voltage Power Supply.
- PASCO High Voltage Power Supply.
- wires.

Procedure:

1. Connect the circuit as shown in **Figs. 4-6**, and switch on power supplies.
2. Set the high voltage power supply (electrode voltage (V_{elec})) to 250 V.
3. Turn the voltage adjust knob of the low power supply clockwise until the right display reads a current of 1.4 A.
4. **Wait a minute** for the cathode to heat up. When it does, you will see the electron beam emerging from the electron gun forming a circle.
5. For electrode voltages from 180 V to 300 V, measure the radius both from the left and right sides of the electrons beam circle and record in **Table I**.
6. Calculate the average value of the radius (r_{avg}) and get r_{avg}^2. Record values.
7. **Plot** a graph of V_{elec} versus r_{avg}^2 from which determine e/m ratio.

Fig. 4: *e/m* setup

Fig. 5: Right (high voltage power supply)



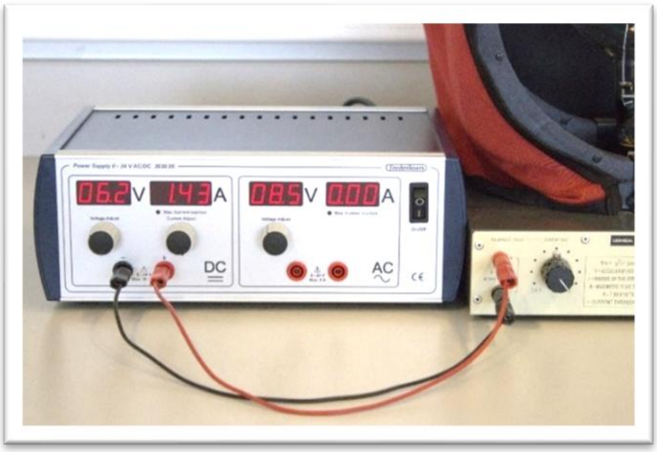


Fig. 6: Left (low voltage power supply)

Section: ....

Date:............................

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KUWAIT UNIVERSITY

Exp. No. (8)

ELECTRON TO MASS RATIO

e/m

Student name:..

Student ID:...

Instructor name:...

Group no.:

Objectives

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Data and analysis of results

Table I

V_{elec} (V)	r_L (cm)	r_R (cm)	r_{avg} (cm)	r_{avg}^2 (cm^2)
180				
210				
240				
270				
300				

- The theoretical value of e/m_{th} =..........................
- The experimental value of e/m_{exp} =........................... (from the graph)
- Percentage error in e/m value:

  $\left|\frac{e/m_{exp} - e/m_{th}}{e/m_{th}}\right| \times 100 =$.................%

- Gently rotate the glass tube horizontally. What do you notice? Explain.

  ....

  ....

- Disconnect the current from the Helmholtz coil. What do you notice?

  Explain. ....

  ....

- Slowly increase and decrease the value of the current in the Helmholtz coil. What effect does this have on the electron beam circle? Explain.

  ……………………………………………………………………………………………

  ……………………………………………………………………………………………

Questions

1. What is the relation between V_{elec} and r^2?

   ……………………………………………………………………………………………

2. What is the effect of reversing the current direction in the Helmholtz coils?……………………………………………………………………………………

3. How does the radius of the electrons beam circular path change with the current I? ……………………………………………………………………………

4. Suppose that the polarity of V_{elec} was set oppositely, what could be the effect on the electrons beam?…………………………………………………………

Discussion and conclusion

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Experiment Nine: Inductance

Objectives

- To get familiar with the behavior of an inductor in an AC circuit.
- To determine the inductance of an inductor.

Introduction

An inductor (L) is defined as an electrical element that is used in most electrical circuits to store energy in the form of magnetic energy when electric current flows through it. It is also known as coil, choke or reactor. Consider an AC circuit (**Fig. 1**) consisting of an inductor L connected in series to a resistor R and to a Function Generator which is an AC power source (V_s).

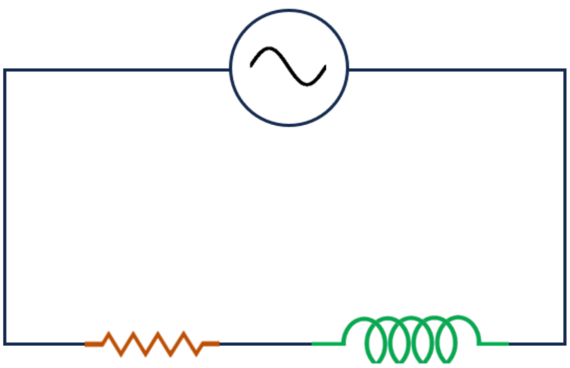

Fig. 1: R-L circuit

The output voltage of the Function Generator may be written as

$$V_s(t) = V_{sm} \sin(\omega t + \phi) \tag{1}$$

and the current delivered to the circuit as

$$I(t) = I_m \sin \omega t \tag{2}$$

where V_{sm} and I_m are the voltage and current amplitudes (or peak values), ω is the angular frequency, which is related to the frequency of power source via $\omega = 2\pi f$, and ϕ is the phase difference between V_s and I, which depends on the details of the circuit.

The voltage across the resistor is $V_R = IR$, and the voltage across the inductor is given by $V_L = L\frac{dI}{dt}$, where L (with units of Henry (H)) is called the inductance. Therefore,

$$V_R = RI_m \sin \omega t = V_{Rm} \sin \omega t \tag{3}$$

$$V_L = L\omega I_m \cos \omega t = V_{Lm} \sin\left(\omega t + \frac{\pi}{2}\right) \tag{4}$$

Based on Eqs. (3) & (4), the voltage across the inductor V_L leads the current I by $\frac{\pi}{2}$, whereas the voltage across the resistor V_R is in phase with the current I as shown graphically in **Fig. 2**. In Eq. (4), $V_{Lm} = L\omega I_m$, that is the quantity $L\omega$ has a unit of Ohm, and is called the reactance of the inductor, $X_L = L\omega$.

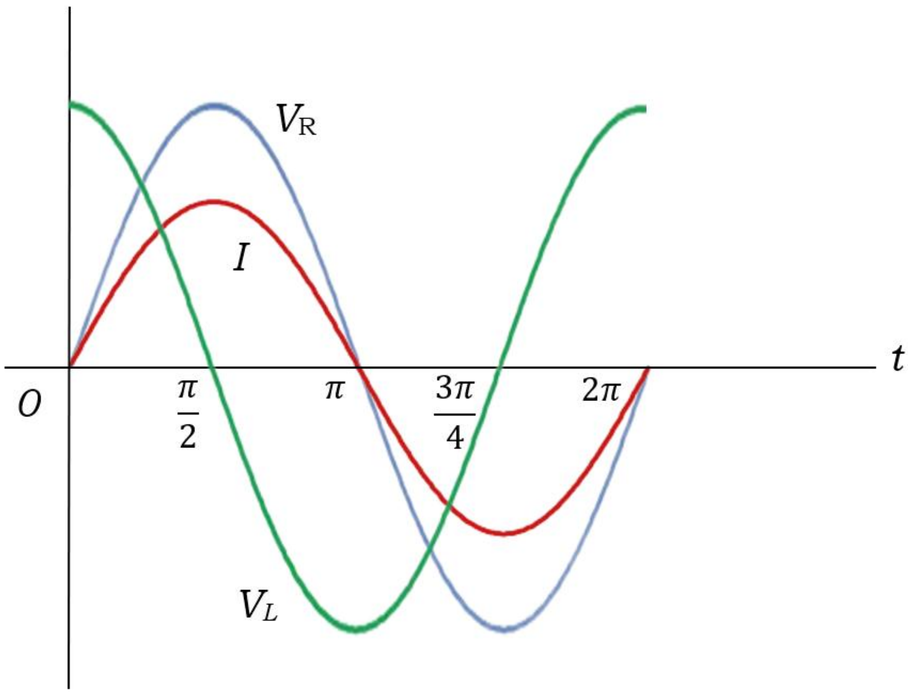

Fig. 2: Phases of V_R and V_L versus the phase of I for an R-L circuit

Phasor diagram is used to represent the sinusoidally varying voltages and currents. **Figure 3** is a phasor diagram representing V_{Rm}, V_{Lm}, and V_{Zm}, where V_{Zm} represents the amplitude of the total voltage across the series combination of resistor and inductor, which is the same as the amplitude V_{sm}.

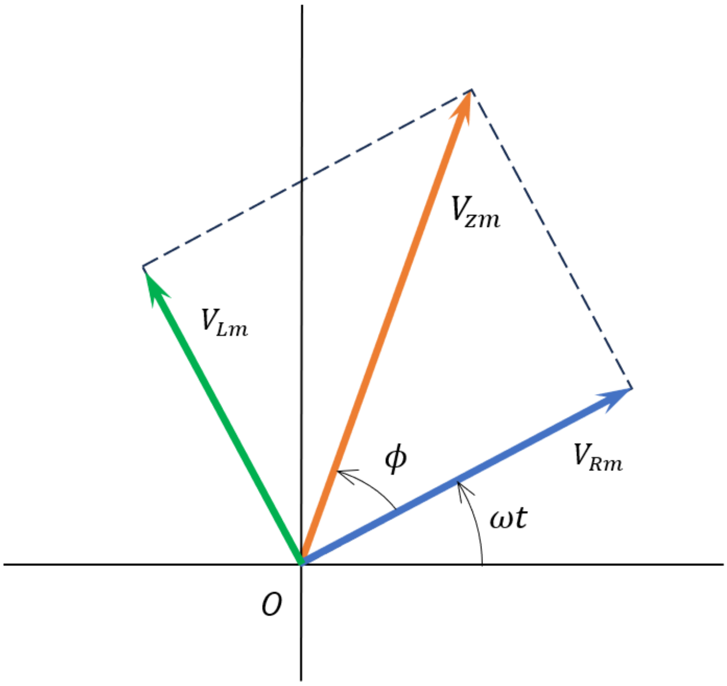

Fig. 3: Phasor diagram

From **Fig.3** we realize that

$$V_{zm}^2 = V_{Rm}^2 + V_{Lm}^2. \tag{5}$$

Equation (5) can be expanded using Ohm's law to get

$$I_m^2 Z^2 = I_m^2 R^2 + I_m^2 X_L^2 \tag{6}$$

canceling I_m^2 from Eq. (6) we get

$$Z^2 = R^2 + X_L^2. \tag{7}$$

where Z (impedance) represents the total resistance of the AC circuit.

If we include the ohmic resistance (r) of the inductor (coil), then

$$Z^2 = (R + r)^2 + X_L^2 \tag{8}$$

Equation (8) sows that the relation between Z^2 and $(R+r)^2$ is linear. Therefore, a plot of Z^2 versus $(R+r)^2$ yields a straight line with slope of 1, where the y-intercept equals to X_L^2.

In this experiment, for given values of R, r, and f, and by measuring the supply voltage V_s, and the current I, the impedance of the circuit Z can be calculated using $Z = V_s/I$. Then X_L can be determined, and the inductance L is calculated from $L = \frac{X_L}{\omega} = \frac{X_L}{2\pi f}$.

It worths mentioning that the voltages measured by the multimeter in this experiment are rms (root mean square) values; but since the rms value is proportional to the amplitude ($V_{rms} = V_{max}/\sqrt{2}$), Eq. (5), hence the rest analysis applies to the measured values.

Equipment

- Instek Function Generator
- Decade Resistance Box
- 1600 turns Inductor (Inductance = 50 mH)
- Multimeters
- Wires.

Procedure

1. Using the **coil labeled 1600**, measure its ohmic resistance r.
2. Connect the circuit given in **Fig.1** as shown in **Fig.4**.
3. Set the frequency of the Function generator to **300 Hz**, and the **Amplitude to maximum**.
4. Set the resistance R of the Decade Resistance Box to 50 Ω.
5. Measure the total voltage V_Z. Record the value in **Table I**.

6. Measure the current I. Record in **Table I**.

7. Calculate $Z = V_Z/I$, Z^2, and $(R + r)^2$. Record in **Table I**.

8. Repeat steps $5 - 7$ varying R from 75 to 150 Ω.

9. **Plot** Z^2 versus $(R + r)^2$, determine the slope and X_L, then calculate L.

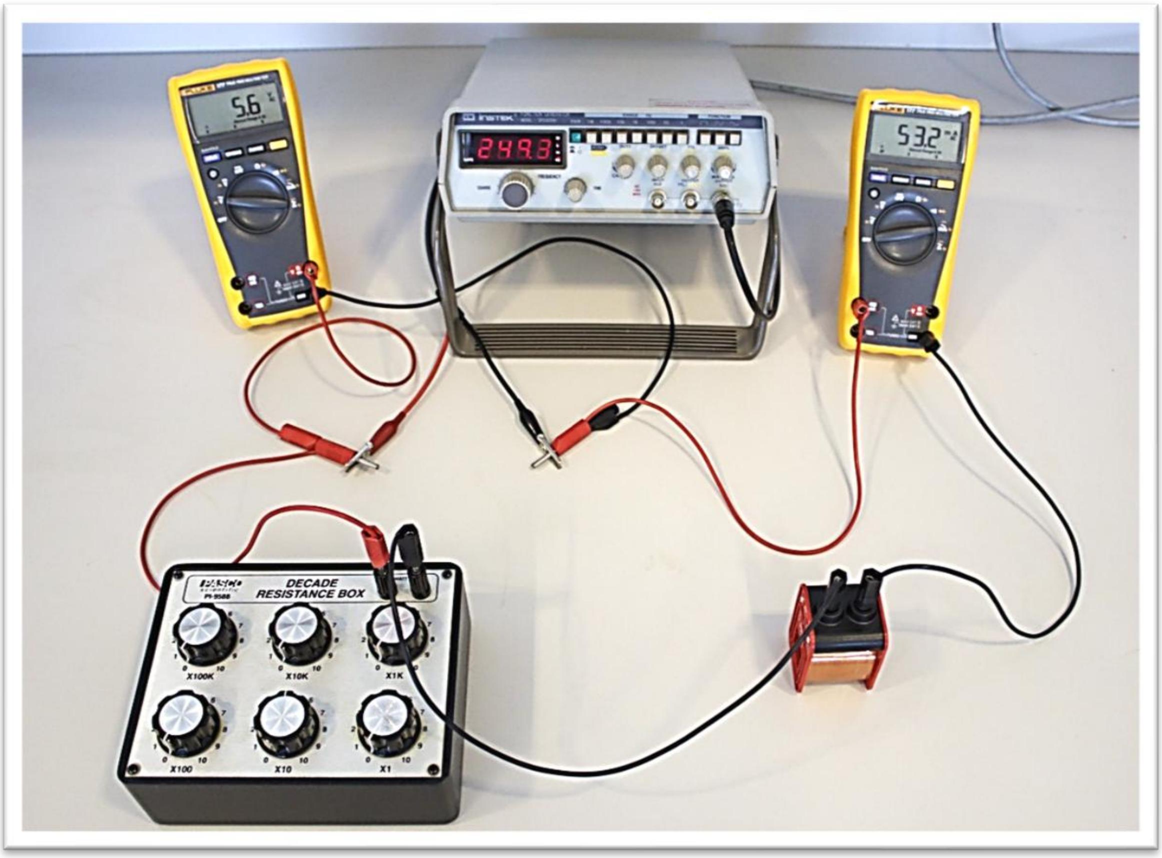

Fig. 4: R-L circuit setup

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KUWAIT UNIVERSITY

Exp. No. (9)

INDUCTANCE

Student name:...

Student ID:...

Instructor name:...

Group no.:

Objectives

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Data and analysis of results

r =………………………

Table I frequency $\boldsymbol{f} = \mathbf{300\ Hz}$

R (Ω)	$(\boldsymbol{R}+\boldsymbol{r})^{2}$ (× $\mathbf{10^{4}}$Ω²)	$\boldsymbol{V_z}$ (V)	I (mA)	Z (Ω)	$\boldsymbol{Z^{2}}$ (× $\mathbf{10^{4}}$Ω²)
50					
75					
100					
125					
150					

(**Note:** *For convenience, it is recommended that both* $(\boldsymbol{R}+\boldsymbol{r})^{2}$ *&* $\boldsymbol{Z^{2}}$ *values in the table be recorded in order of 4*)

- Slope of the curve (graph): slope = ………………………
- Inductance determined from graph: L_{exp} = ……………………………………
- Percentage error in the Indutance:

$$\left|\frac{L_{exp}-L_{th}}{L_{th}}\right| \times 100 = \ldots\ldots\ldots\ldots\%\qquad (L_{th} = 50\ \text{mH})$$

Questions

1. What type of energy does the inductor store?..
2. For an R-L circuit, why $V_z \neq V_{R+r} + V_L$ although the inductor & the resistor are in series?..
3. How is Z^2 related to $(R+r)^2$?

   ....

4. What happens if the AC power source is replaced with a DC one?

   ....

5. Does the voltage across the inductor V_L leads or lags the current I by $\frac{\pi}{2}$?

   ....

6. If the frequency of the source is increased, what effect this would have on the inductive reactance and the impedance of the circuit?

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Discussion and conclusion

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Exp. Ten: Transformer

Objectives

- To study the operation of a transformer.
- To examine the effect of core configuration on the transformer voltage gain.
- To compare step-up and step-down transformers and between no-load and full-load operation.

Introduction

The transformer consists of two coils (or windings) wound around a soft iron coil (see **Fig. 1**). One is referred to as the primary coil, with N_1 turns, and the other as the secondary coil, with N_2 turns. The primary coil is connected to an alternating-current (AC) source with electromotive-force (emf) $\mathcal{E}_1$, and the secondary is connected to a resistive load.

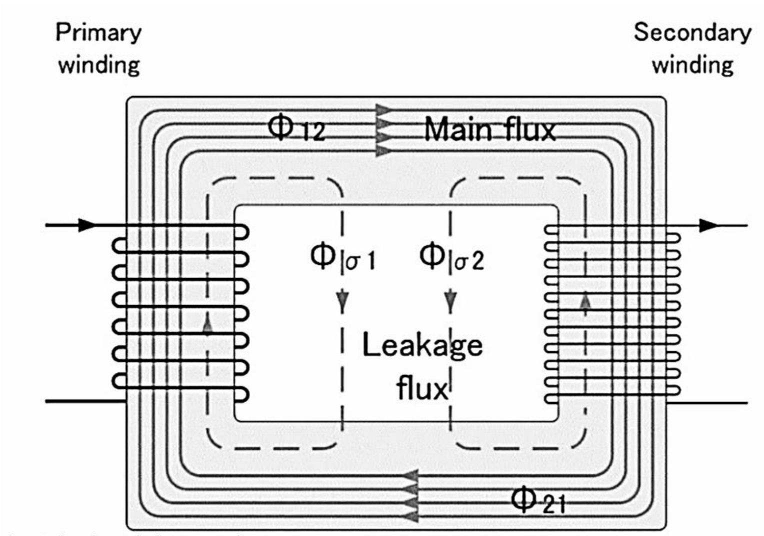

Fig. 1: The basic Transformer

According to Faraday's law, an alternating current in the primary coil induces a self-alternating magnetic flux Φ_B, which leads to an induced ε_1, such that

$$\varepsilon_1 = -N_1 \frac{d\Phi_B}{dt} \quad (1)$$

The magnetic flux through the primary coil is linked to the secondary coil through the iron core. Thus, the magnetic flux rate of change is the same for both coils. Therefore, using Eq.(1), we get

$$-\frac{d\Phi_B}{dt} = \frac{\varepsilon_1}{N_1} = \frac{\varepsilon_2}{N_2} \quad (2)$$

If the windings have zero resistances, the induced emfs ε_1 and ε_2 are equal to the terminal voltages across the primary and the secondary coils V_1 and V_2 respectively. Therefore, using Eq. (2) we get

$$V_2 = V_1 \left(\frac{N_2}{N_1}\right) \quad (3)$$

Now, if $N_2 > N_1$, we speak of a step-up transformer; and if $N_2 < N_1$, we speak of a step-down transformer. The voltage gain, G, is defined as the ratio between the output, to the input voltages, or

$$G = \frac{V_2}{V_1} \quad (4)$$

(which equals N_2/N_1 for ideal transformers, but in practice, part of the magnetic flux Φ_B generated in the primary coil leaks out of the iron core (leakage flux) see **Fig. 1**, hence, $G \neq N_2/N_1$). For a step-up transformer $G > 1$, and for a step-down $G < 1$.

For no load operation, no current exists in the secondary coil and therefore, no power is delivered to the transformer, and the primary coil acts as a pure inductance, whereas, if a load (resistor) is connected to the secondary coil, a current, I_2, is set through the secondary coil, and the two windings appear to be as a fully coupled mutual inductance.

The overall view provided by the conservation of energy principle for an ideal transformer with a resistive load:

$$P_{out} = P_{in} \tag{5}$$

where $P_{in} = V_{in}I_{in}$, and $P_{out} = V_{out}I_{out}$ are the input and output powers.

Transformer efficiency (η) may be expressed as

$$\eta = \frac{P_{out}}{P_{in}} \times 100 \tag{6}$$

In practice no transformer has 100% efficiency, due to power losses. Some of the main reasons for these losses are the resistance of the coils, the magnetic leakage, and the hysteresis losses (due to magnetization properties of the core).

One of the applications of transformers is in the power-generating stations, where step-up transformers are used at the terminals of the station (to reduce i^2R losses in the power transmission lines). Near the consumer, step-down transformers are used to lower the voltage to values suitable for use in home or industry.

Equipment

- The PASCO SF-8616 Basic Coils Set.
- Low voltage ac power supply (PASCO Model SF-9582).
- Resistance box.
- Banana connecting leads for electrical connections.
- Multimeters (4).

Procedure

Part one (*core configuration*)

1- Set up the two coils labeled 400 as shown in **Fig.2** (no core is used).

2- Set the power supply voltage to **5.0 V**.

3- Measure the input voltage V_{in}, and the output voltage V_{out}, then calculate the voltage gain **G** and record in **Table I**.

4- Repeat step 3, changing the core configuration as shown in **Fig.3**.

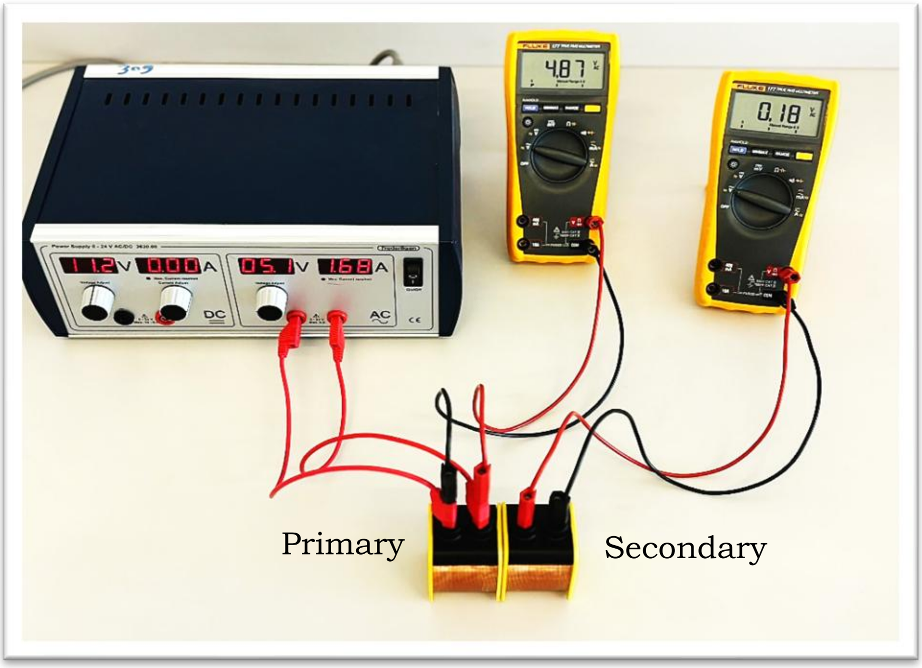

Fig. 2: Setup to check best core configuration

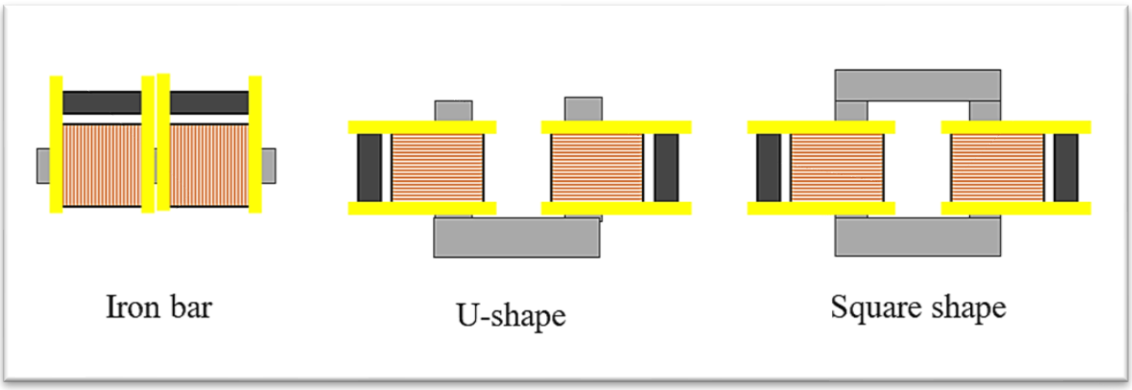

Fig. 3: Core configurations

Part two (*Step-up vs step-down transformer*)

1- Use the core configuration that gave the maximum voltage gain in **part 1**, set up the coils as shown in **Fig.4**. Set the power supply voltage of to **5.0 V**.

2- Fix the **primary coil to 400-turns** and change the **secondary** coil according to **Table II**, measure the input voltage V_{in}, and the output voltage V_{out}, then calculate the voltage gain **G** and record in **Table II**.

3- Fix the **primary coil to 3200-turns** and change the **secondary** coil according to **Table III**, measure the input voltage V_{in}, and the output voltage V_{out}, then calculate the voltage gain **G** and record in **Table III**.

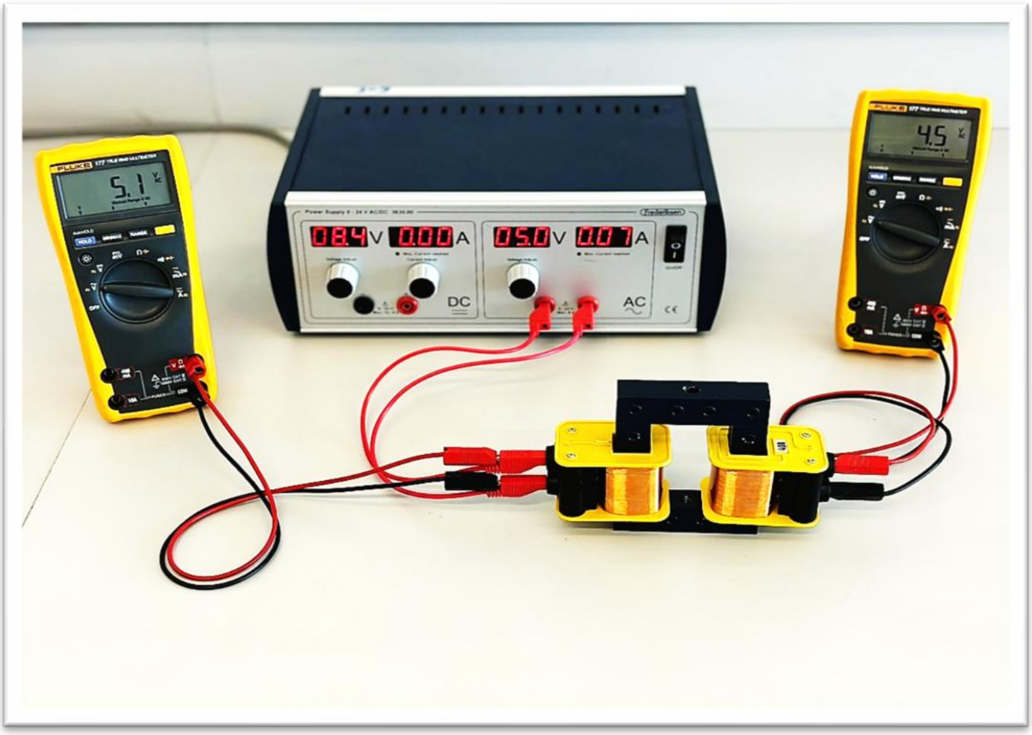

Fig. 4: Setup to examine step-up & step-down transformers

Part three (*Power efficiency* η)

1- Set up the circuit given in **Fig.5** as shown in **Fig.6**, using **400-turns** coil as the **primary**, and **1600-turns** coil as the **secondary**.

2- Connect 2 more multimeters to measure the voltages, as shown in **Fig.7**.

3- Set the resistance (of the Decade Resistance Box) to 1000 Ω.

4- **Measure** the input and output **voltages** and **currents**. Record in **Table IV**.

5- **Calculate** the input and output **powers**. Calculate the **voltage gain** G, and the **power efficiency** η. Record values in **Table V**.

6- **Repeat** steps 4 & 5 for resistance values given in the two **Tables**.

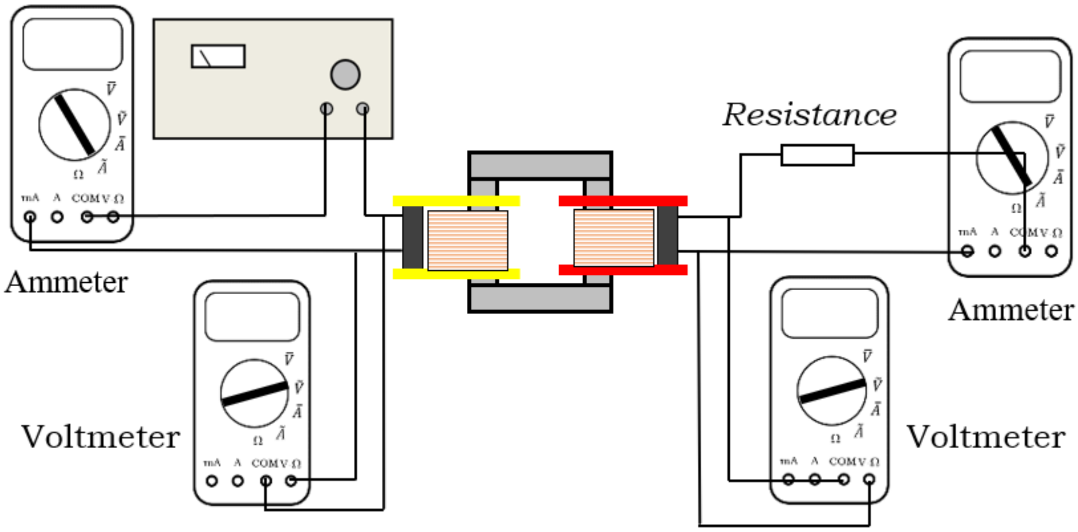

Fig. 5: Determining power efficiency of the Transformer

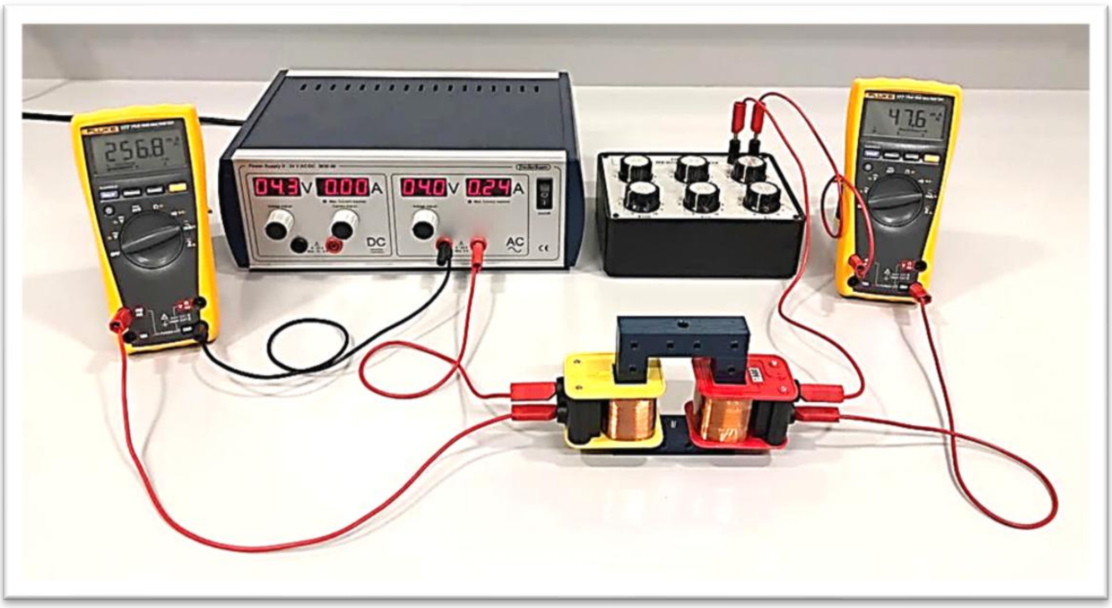

Fig. 6: Connections photo for circuit given in **Fig.5.** Includes 2 Ammeters only: the left, to measure I_{in}, and the right to measure I_{out}

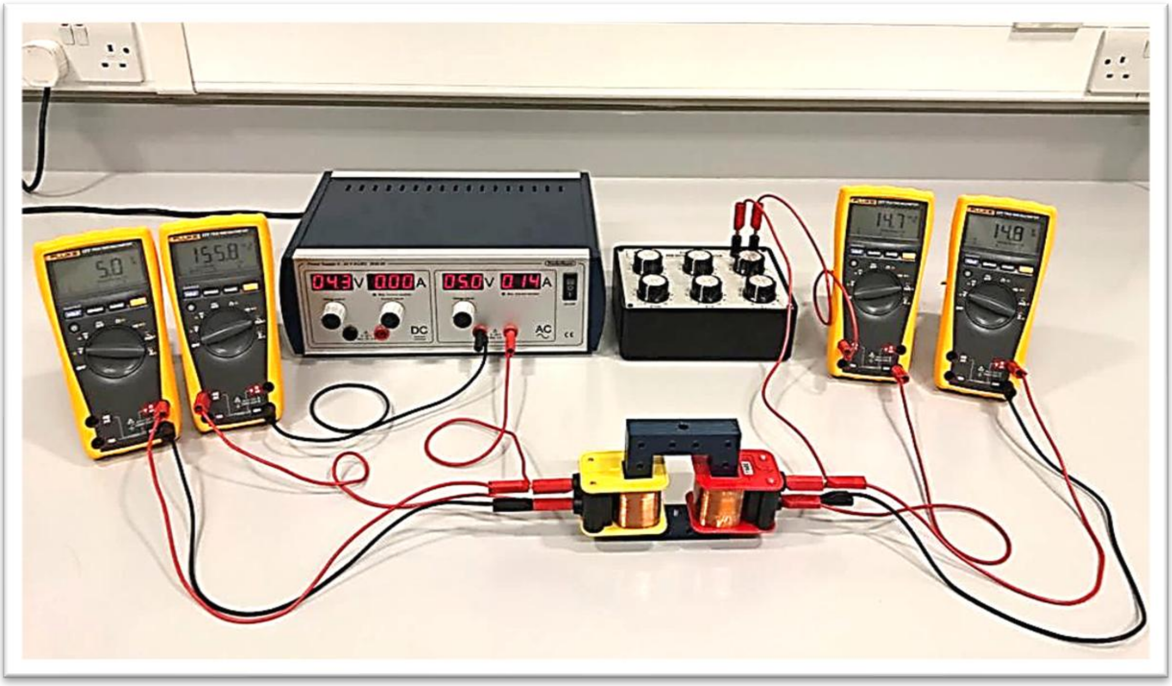

Fig. 7: Setup as in **Fig. 6** with 2 Voltmeters added: most left, to measure $\boldsymbol{V_{in}}$**,** and most right to measure $\boldsymbol{V_{out}}$

Section: ……………………..

Date:………………………….

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Exp. No. (10)

TRANSFORMER

Student name:……………………………………………..

Student ID:……………………………………………..

Instructor name:…………………………………………..

Group no.:

Objectives

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Data and analysis of results

Table I (*both coils of 400-turns*) $\boldsymbol{V_s}$ **= 5.0 V**

Core	V_{in} (V)	V_{out} (V)	*G*
NO			
Iron bar			
U-shape			
Square-shape			

Table II (*step-up*) $\boldsymbol{V_s}$ **= 5.0 V**

Primary	Secondary	V_{in} (V)	V_{out} (V)	*G*
400	800			
400	1600			
400	3200			

Table III (*step-down*) $\boldsymbol{V_s}$ **= 5.0 V**

Primary	Secondary	V_{in} (V)	V_{out} (V)	*G*
3200	1600			
3200	800			
3200	400			

Table IV (*voltages & currents*) V_s **= 5.0 V**

R (Ω)	V_{in} (V)	I_{in} (mA)	V_{out} (V)	I_{out} (mA)
1000				
1200				
1400				
1600				
1800				

Table V (*power efficiency*)

R (Ω)	P_{in} (W)	P_{out} (W)	G	η
1000				%
1200				%
1400				%
1600				%
1800				%

Questions

1- Why does the square core configuration give the maximum voltage gain?

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2- What are Transformers used for?

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3- Can a transformer input be DC?……………………Why?………………………

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4- In practice no transformer is 100% efficient. Why?

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5- At the terminals of the power-generating stations, step-up transformers are used. Explain the reason.

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Discussion and conclusion

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